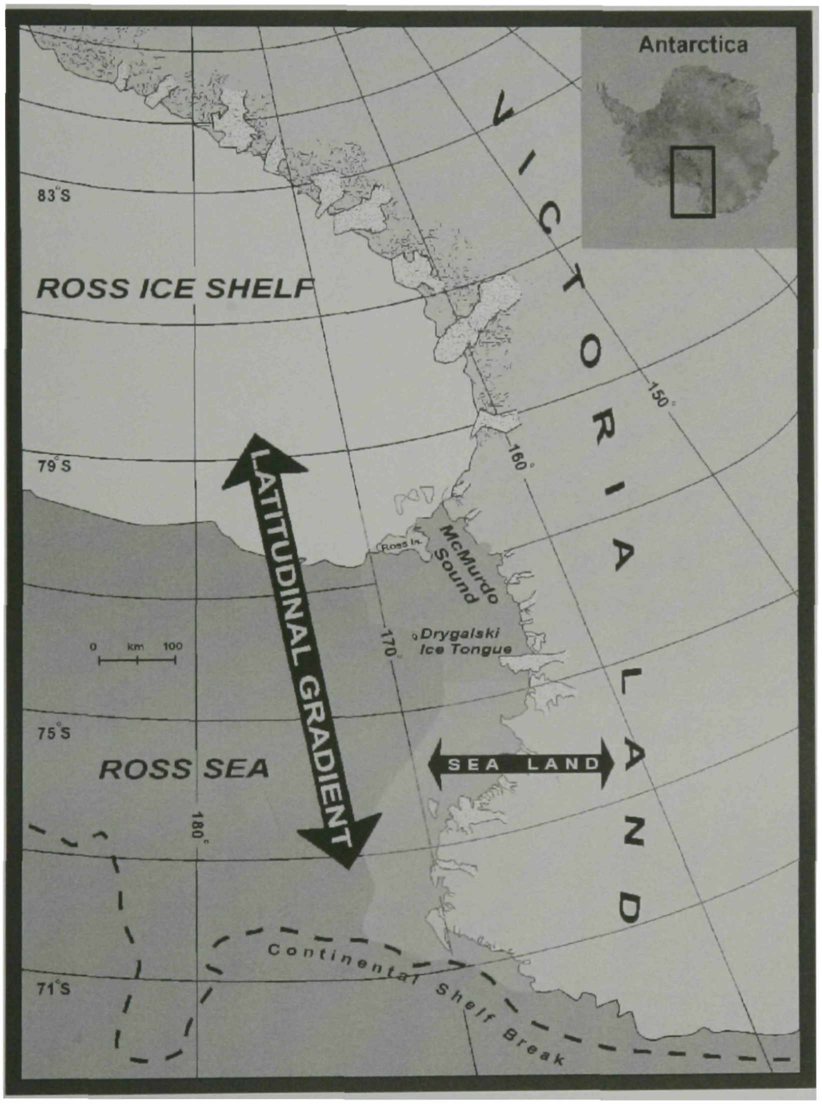
LIBRARY COPY

Latitudinal Ecosystem (LAT-ECO) Responses to Climate Across Victoria Land, Antarctica



BPRC REPORT No. 20

Report of a National Science Foundation Workshop

BYRD POLAR RESEARCH CENTER
THE OHIO STATE UNIVERSITY

BYRD POLAR RESEARCH CENTER
Report No. 20

LATITUDINAL ECOSYSTEM (LAT-ECO) RESPONSES TO CLIMATE ACROSS VICTORIA LAND, ANTARCTICA

REPORT OF A NATIONAL SCIENCE FOUNDATION WORKSHOP

Victoria Land, Antarctica, Coastal Biome: Marine-Terrestrial Biocomplexity Across a High Latitudinal Environmental Gradient

Byrd Polar Research Center, The Ohio State University
Columbus, Ohio 26-29 April 2001

2001

ISSN: 0896-2472

ACKNOWLEDGEMENTS

The workshop on *Victoria Land, Antarctica: Coastal Biome: Marine-Terrestrial Biocomplexity Across a High Latitude Environmental Gradient* and this report have been generously supported by the National Science Foundation, Office of Polar Programs, in conjunction with NSF Education and Human Resources biocomplexity program (NSF-OPP 0084037). We gratefully acknowledge the enthusiastic support of the scientists, program managers and support personnel who have continued to contribute to the development of this interdisciplinary research initiative.

Published in 2001 by the

BYRD POLAR RESEARCH CENTER

This report may be cited as:

Berkman, P.A. and L.R. Tipton-Everett (eds.) 2001. *Latitudinal Ecosystem (LAT-ECO) Responses to Climate Across Victoria Land, Antarctica.* Report of a National Science Foundation Workshop. BPRC Report No. 20, Byrd Polar Research Center, The Ohio State University, Columbus, Ohio, 152 pages.

The Byrd Polar Research Center Report Series is edited by Lynn Tipton-Everett.

Copies of this and other publications of the Byrd Polar Research Center are available from:

Publication Distribution Program
Byrd Polar Research Center
The Ohio State University
1090 Carmack Road
Columbus, Ohio 43210-1002
Telephone: 614 292-6715
Fax: 614 292-4697

Latitudinal Ecosystem (LAT-ECO) Responses to Climate Across Victoria Land, Antarctica

Report of a National Science Foundation Workshop
Byrd Polar Research Center, The Ohio State University
Columbus, Ohio, 26-29 April 2001

STEERING COMMITTEE

Paul Arthur Berkman, Chair
Byrd Polar Research Center, The Ohio State University

W. Berry Lyons
Byrd Polar Research Center, The Ohio State University

Ross D. Powell
Department of Geology and Environmental Sciences, Northern Illinois University

John C. Priscu
Department of Biological Sciences, Montana State University

Walker O. Smith
Virginia Institute of Marine Sciences, College of William and Mary

Edwin D. Waddington
Department of Earth and Space Sciences, University of Washington

20 October 2001

TABLE OF CONTENTS

BIOCOMPLEXITY RESEARCH INITIATIVE

EXECUTIVE SUMMARY 1
1. INTERDISCIPLINARY RESEARCH FRAMEWORK 5
   1.1 Biocomplexity 5
   1.2 Unique and Exceptional Features 10
   1.3 Climate, Environmental and Ecosystem Variability 11
2. BACKGROUND RESEARCH 14
   2.1 Climate, Environmental and Ecosystem Dynamics 14
      Space and Time Scales 14
      Oceanography 17
      Sea Ice 18
      Meteorology 20
      Glaciology 21
   2.2 Ecosystem and Environmental Zones 23
      Marine Zone 23
      Marine-Terrestrial Transition Zone 28
      Terrestrial Zone 29
3. HUMAN DIMENSIONS 31
   3.1 International Cooperation and Management 31
   3.2 Public Outreach, Engagement and Education 33
4. SCIENTIFIC AND LOGISTIC IMPLEMENTATION 34
   4.1 Research Coordination in the United States 34
   4.2 International Research Coordination 34
   4.3 Next Steps 35

APPENDIX 1

ABSTRACTS 39

The Possible Contribution of CLIMA Project to the Victoria Land Project
   Andrea Bergamasco, Serena Fonda Umani and Giancarlo Spezie 39
Meteorological Processes Affecting Victoria Land and the Data Available to Study Them
   David H. Bromwich and Andrew J. Monaghan 40
Italian Report on the Victoria Land Latitudinal Gradient Project
   Riccardo Cattaneo-Vietti 44

Research Interests in the Victoria Land Project Benthic Communities Structure and Dynamics
Riccardo Cattaneo-Vietti 53
Research Interests in the Victoria Land Project - Echinoderm and Mollusc Population Structure, Reproductive Ecology, and its Consequence in Population Isolation
Mariachiara Chiantore 55
Late-Holocene Glacial Conditions in the Ross Sea Embayment
Howard Conway 56
Ecotoxicology and Ecophysiology
1) Simonetta Corsolini, Silvia Olmastroni and Silvano Focardi 58
2) Marco Nigro and Francesco Regoli 59
Variability in the Trophic Ecology of the Ross Sea: Linking Modern Variability to Signals in the Fossil Record
Daniel P. Costa 61
Some Italian Research Institutions and PI's Interested in Participating in the Victoria Land Transect Project
Guido di Prisco 63
Abstract: Research Interests in Relation to Victoria Land Transect
Peter T. Doran 65
Documenting Latitudinal and Depth Gradients for Fishes Along the Victoria Land Coast
Joseph T. Eastman 67
Penguin Paleohistory and Climate Change in the Ross Sea Region
Steven D. Emslie 71
Ecology of Sea Ice Biota: Characteristics and Dynamics in Across-Shelf Environmental Gradients
Christian H. Fritsen 74
Scaling in Space and Time: Plant Carbon Cycling in an Arctic River Basin
John E. Hobbie 75
Gradients of Climate in Controlling Shallow-Water Microbial Communities Across Victoria Land
Ian Hawes, Clive Howard-Williams, Anne-Maree Schwarz and Doug Mountford 76
Sea Ice Characteristics and Processes in the Southwestern Ross Sea
Martin O. Jeffries, Kim Morris and Nickolai Kozlenko 78
Victoria Land Abstract
Stacy Kim 90
Spatial and Temporal Changes in the Ross Sea Physical Environment Since the Last Ice Sheet Retreat
Kathy Licht 93
Fast Ice Microbial Communities Along the Victoria Land Coast
Michael Lizotte 95
A High Resolution $\delta^{18}0$ Record of Growth Banding in *Adamussium Colbecki*: A Proxy for Reconstruction of Coastal Salinities and Continental Temperatures on Annual to Century Time Scales
Kyger C Lohmann, Paul Arthur Berkman and Maria C. Marcano 96

Victoria Land Abstract
W. Berry Lyons ... 99
The International Trans Antarctic Scientific Expedition (ITASE) Challenge
Paul A. Mayewski, Chair ITASE ... 100
Antarctic Multi-Decadal Scale Variability Over the Last 500 Hundred Years
Paul A. Mayewski ... 102
Using GIS to Develop Geospatial Datasets for Understanding Environmental Processes in the Victoria Land, Antarctica, Coastal Biome
Carolyn J. Merry ... 103
Victoria Land Abstract
Daryl Moorhead ... 106
The Italian Antarctic Meteo-Climatological Observatory
A. Pellegrini ... 107
Marine High-Resolution Holocene Environmental Change Records and Geological Processes from the Victoria Land Coast: Establishing a Base-Line for the Modern Marine Ecosystem
Ross D. Powell ... 110
Victoria Land Abstract
John C. Priscu ... 112
Victoria Land Abstract
Reed Scherer, Charlotte Sjunneskog and Ala Aldahan ... 113
Victoria Land Abstract
Bruce D. Sidell ... 114
The Palmer LTER: A Long-Term Ecological Research (LTER) Program in the Western Antarctic Peninsula (WAP) Region
Raymond C. Smith ... 116
Work in Progress and Linkages with WAIS Biocomplexity Initiative
Walker Smith ... 117
The Ice Core Record of Victoria Land Climate and Biocomplexity
Eric J. Steig ... 119
Impacts of Climate on Ecosystems: Coastal Undersea Benthic Environments
Alf Norkko, Simon Thrush, Neil Andrew, Ian Hawes and Anne-Maree Schwarz ... 121
Climate, Ice and Biological Change in Victoria Land
Edwin D. Waddington ... 123
Terrestrial (Soil) Ecosystems
Diana Wall ... 124

APPENDIX 2
REFERENCES CITED ... 127

APPENDIX 3
PARTICIPANT LIST ... 149

BIOCOMPLEXITY RESEARCH INITIATIVE

EXECUTIVE SUMMARY

This report is derived from the interdisciplinary discussion regarding the

Victoria Land, Antarctica, Coastal Biome:
Marine-Terrestrial Biocomplexity Across a High-Latitude Environmental Gradient

that was convened through a National Science Foundation workshop from 26-29 April 2001 at the Byrd Polar Research Center, The Ohio State University (http://www-brpc.mps.ohio-state.edu/victorialand). The principal goal of this workshop was to establish common research themes among diverse Earth system scientists with a view toward:

1. providing the scientific and logistic framework for a coordinated interdisciplinary research initiative along the north-south trending Victoria Land coastal region of Antarctica; and

2. investigating marine-terrestrial biocomplexity along the latitudinal environmental gradient of Victoria Land, Antarctica, as a global barometer of climate change.

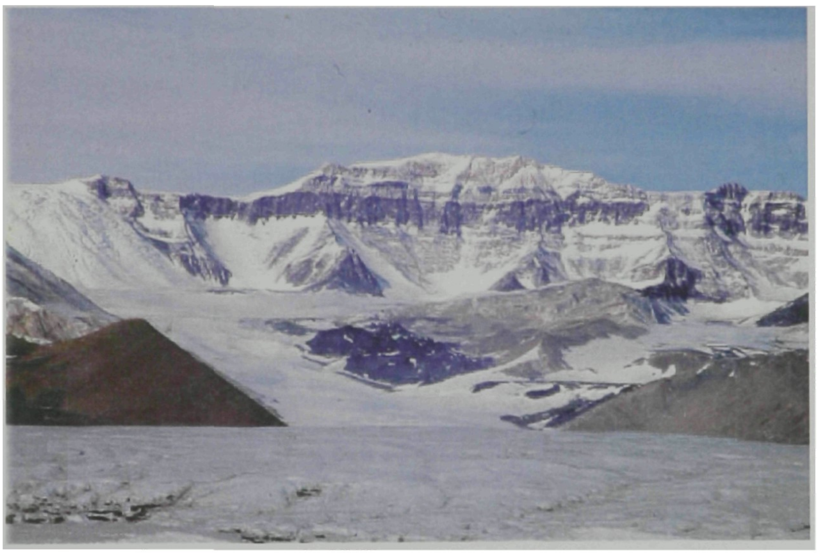


FIGURE 1: Victoria Land, Antarctica, viewed from the southwestern Ross Sea (P.A. Berkman)

This workshop built on earlier planning sessions hosted by Antarctica New Zealand (Peterson and Howard-Williams 2001), the Programma Nazionale di Richerche in Antartide (Cattaneo-Vietti, this report) and the United States Antarctic Program which involved a broad suite of discussions about developing a Victoria Land latitudinal gradient initiative (see http://www-bprc.mps.ohio-state.edu/victorialand). Based on these previous discussions (Box 1), an interdisciplinary steering committee from the United States (editors for this report) was established to coordinate the discussion with a view toward developing an interdisciplinary and international research initiative that could be supported by the United States Antarctic Program and National Science Foundation in collaboration with other national Antarctic programs and the international scientific community.

BOX 1

HISTORY OF INTERDISCIPLINARY AND INTERNATIONAL DISCUSSIONS FOR DEVELOPING A VICTORIA LAND LATITUDINAL GRADIENT RESEARCH INITIATIVE

(http://www-bprc.mps.ohio-state.edu/victorialand)

JANUARY 1999 Discussions begin between Paul Berkman (US), Riccardo Cattaneo-Vietti (IT), Mariachiara-Chiantore (IT) and Clive Howard-Williams (NZ)

MARCH 1999 Clive Howard-Williams (NZ) - Annual New Zealand Antarctic Science Workshop.

APRIL 1999 Ian Goodwin (AU) and Ross Powell (US) - Scientific Committee on Antarctic Research (SCAR)-International Geosphere-Biosphere Program (IGBP) Global Change in the Antarctic (GLOCHANT) Meeting.

MAY 1999 Robertta Marinelli (US) - SCAR-Regional Sensitivity to Climate Change in Antarctic Terrestrial Environments (RISCC) Workshop in Madrid, Spain.

MAY 1999 Paul Berkman (US) - SCAR-Antarctic Ice Margin Evolution (ANTIME) Antarctic Radiocarbon Workshop, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

MAY 1999 Clive Howard-Williams and Dean Petterson (NZ) - ***"Integrating New Zealand's Research Efforts in Antarctica Using the Concept of a Latitudinal Gradient."*** A proposal submitted to Antarctica New Zealand's Science Strategy Theme (Life in Extreme Environments).

JUNE 1999 Roberto Cattaneo-Vietti (IT), Paul Berkman, Mariachiara Chiantore (IT), Francesco Regoli (IT), David Garton (US) and Marco Nigro (IT) - ***"The Victoria Land Coastal Transect Project."*** *SCAR-EASIZ Meeting*. Bremerhaven, Germany.

SEPTEMBER 1999 Paul Berkman - West Antarctic Ice Sheet Meeting, Sterling, Virginia.

FEBRUARY 2000 Paul Berkman, Berry Lyons (US), John Priscu (US), Walker Smith (US) and Ed Waddington (US) - ***"The Victoria Land, Antarctica, Coastal Biome: Marine-Terrestrial Biocomplexity Across a High-Latitudinal Environmental Gradient."*** A proposal to the National Science Foundation (NSF), Biocomplexity Program.

JUNE 2000 Berry Lyons - SCAR-RISCC Meeting, Johannesburg, South Africa.

JUNE 2000 Roberto Cattaneo-Vietti (convener)- ***"Victoria Land Coastal Program"*** Meeting, Siena, Italy.

JULY 2000 SCAR Biology Working Group, Geology Working Group and Committee of Managers of National Antarctic Programs, Tokyo, Japan.

AUGUST 2000 Clive Howard-Williams and Dean Petterson (conveners) - ***"The Latitudinal Gradient Project"*** Workshop, Christchurch, New Zealand, supported by Antarctica New Zealand

SEPTEMBER 2000 Paul Berkman (convener) - Workshop planning session at the West Antarctic Ice Sheet (WAIS) meeting in Sterling, Virginia.

APRIL 26-29, 2001 Paul Berkman, Berry Lyons, Ross Powell, John Priscu, Walker Smith and Ed Waddington (conveners) - "***Victoria Land, Antarctica, Coastal Biome: Marine-Terrestrial Biocomplexity Across a High Latitudinal Environmental Gradient***" Workshop at the Byrd Polar Research Center, The Ohio State University, Columbus, Ohio, supported by the NSF Office of Polar Programs

AUGUST 25-26, 2001 Paul Berkman (convener) Workshop on ***"Latitudinal Ecosystem and Environmental Variability Across Victoria Land"*** convened in conjunction with the SCAR Symposium on Antarctic Biology, Amsterdam, The Netherlands.

The steering committee collaborated in identifying participants for the workshop based on their backgrounds; interests; collegial personalities; research experiences; familiarity with relevant datasets; and diversity of perspectives from minorities, women and young scientists. The steering committee also organized the specific thematic sessions for workshop presentations, breakout groups, writing sessions and discussions. With their effective contribution, this workshop involved nearly forty United States, Italian and New Zealand scientists (Appendix 3: List of Participants) who are studying:

- limnology and oceanography;
- marine and terrestrial ecology and paleoecology;
- meteorology, remote sensing analyses and climate modeling;
- glaciology and geomorphology;
- geochemistry and geochronology;
- sediment- and ice-core paleoclimatology; and
- geographic information system analyses and information management.

within the context of the National Science Foundation biocomplexity program (http://www.nsf.gov/home/crssprgm/be/ere_be-competitions.html) to develop *new collaborations of scientists from a broad spectrum of fields*:

> *to better understand the complex interplay of biological, chemical, and physical components of the environment* [in a manner that involves] *quantitative approaches, education, and global perspectives.*

Each of the participants contributed an extended abstract that is discussed in the following sections and printed in Appendix 1 (Extended Abstracts) and Appendix 2 (Citations).

The basic agenda and anticipated products from this Victoria Land workshop involved marine ecosystem and environmental dynamics on Day 1; terrestrial ecosystem and environmental dynamics on Day 2; and information integration during Days 3 and 4. Each day involved three keynote presentations in the morning followed by disciplinary, interdisciplinary and group discussion sessions in the afternoon. We would like to thank the following individuals for their excellent keynote presentations: Martin Jeffries, Daniel Costa and Kathy Licht (Day 1); Diana Wall, Peter Doran and Howard Conway (Day 2); and John Hobbie, Eric Steig and Carolyn Merry (Day 3). We also thank Polly Penhale (United States Antarctic Program), Clive Howard-Williams (New Zealand) and Riccardo Cattaneo-Vieti (Italy) for their informative presentations on national Antarctic program interests in the Victoria Land research initiative during Day 1. We also thank David Bromwich, Berry Lyons, Paul Mayewski, Ross Powell and Ray Smith for sharing helpful information on affiliated global change research programs on Day 2 and interdisciplinary programs on Day 3. Leaders and rapporteurs for the afternoon discussions involved nearly half of the workshop participants and we would like to thank these individuals for their effective contributions. Information from these presentations and discussions provides the basis for addressing the workshop objectives described in Box 2.

This workshop was made possible by a grant from the National Science Foundation (NSF-OPP No. 0084037). We thank the Office of Polar Programs and especially the program managers from polar biology and medicine (Polly Penhale); polar glaciology (Julie Palais) and polar geology (Scott Borg) at the National Science Foundation for their generous support. We also thank Lynn Everett for assisting with the overall logistics as well as Lynn Lay, Jeanne Jaros, Dave Lape and Joshua Everett for contributing to the smooth operation of the workshop and preparation of this report.

Most of all - we would like to thank all of the workshop participants as well as interested members of the research community who were unable to attend for sharing their creativity, enthusiasm and insights about implementing an interdisciplinary research initiative along the latitudinal gradient of Victoria Land, Antarctica. The collection of ideas from these individuals is represented in this report.

BOX 2 OBJECTIVES OF THE VICTORIA LAND LATITIDUNAL GRADIENT WORKSHOP AT THE BYRD POLAR RESEARCH CENTER, 26-29 APRIL 2001	
OBJECTIVE 1	Compile existing data, maps, figures, tables, geographic information systems and publications regarding the components, dynamics and chronologies of terrestrial and marine: **Ecosystems** (e.g. species' production, biomasses, morphologies, diversities, interactions, energetics, biogeochemical features and associated fossil chronologies); and, **Environments** (e.g. current and wind vectors; air- and water-mass characteristics; lake- and sea-ice conditions; stream flows and lake levels; topography and bathymetry; glacial geomorphology; solar and ultraviolet radiation; and associated environmental chronologies); across the latitudinal gradient of Victoria Land over various spatial and temporal scales from the present through the last glacial cycle.
OBJECTIVE 2	Integrate the existing data (see Objective 1) to assess marine-terrestrial: **Ecosystem coupling** related to sea-ice coverage and regional hydrology over seasonal to millennial time scales across Victoria Land; and **Ecosystem dynamics** associated with environmental gradients and transition zones across Victoria Land which reflect global climate dynamics;
OBJECTIVE 3	Identify potential emergent phenomena in coastal marine and terrestrial ecosystems across the latitudinal gradient of Victoria Land (see Objectives 1 and 2) to provide: **'Sentinels'** for predicting local human impacts (such as pollution) and global environmental changes (such as increased ultraviolet radiation flux and global warming);
OBJECTIVE 4	Design an interdisciplinary science plan for assessing marine and terrestrial ecosystem and environmental variability over different time and space scales along the latitudinal gradient of Victoria Land, Antarctica (see Objectives 2 and 3) in relation to natural and anthropogenic impacts.

There we four were lying thousands of miles to the southward of the great struggling world, vast, stern Victoria Land...

Carsten Egeberg Borchgrevink, 1901. First on the Antarctic Continent. Being an Account of the British Antarctic Expedition 1898-1900. George Newnes, London.

1. INTERDISCIPLINARY RESEARCH FRAMEWORK

1.1 Biocomplexity

Coastal zones of continents and oceans - where terrestrial and marine ecosystems interact - are regions of high biological and physical diversity which generally are heavily utilized by human populations. Consequently, dynamic interfaces between marine and terrestrial ecosystems *"makes the coastal zone particularly vulnerable to global change as a consequence of the direct (physical disturbance, pollution, etc.) and indirect (climate) effects of man"* (Holligan and Reiners 1992). Distinguishing natural and anthropogenic impacts in coastal zones and throughout the Earth system is a major challenge of science in our global society (Berkman 2002). The Antarctic coastal zone, while utilized by humans to a limited extent (Benninghoff and Bonner 1985), is among the most pristine regions on the planet for unambiguously assessing such global changes. The purpose of this introduction is to describe the workshop context and consideration for developing an interdisciplinary and international biocomplexity research initiative along the latitudinal gradient of Victoria Land, Antarctica.

The Victoria Land coastal biome of Antarctica is defined by the complex of adjacent terrestrial and marine ecosystems which occupy permanently ice-free oases and outcrops on land as well as polynyas, periodically open-water habitats and ice shelves in the ocean across the latitudinal environmental gradient from Cape Adare (≈72°S) to McMurdo Sound (≈78°S). South of McMurdo Sound, there are additional terrestrial outcrops and marine habitats under the Ross Ice Shelf which also exist across the latitudinal gradient of Victoria Land to ≈86°S, but with different ecosystem coupling characteristics than in the coastal zone of the western Ross Sea where marine habitats are periodically exposed to open water (Fig. 2).

Terrestrial ecosystems of Antarctica have a paucity of life forms compared to those on all other continents, with a total diversity among all identified taxa (i.e. protozoa, rotifers, tardigrades, nemotodes, arthropods, algae, fungi, lichens, liverworts, mosses and flowering plants) of around 1000 species - the largest of which is a terrestrial arthropod a couple millimeters in dimension (Block 1984). Consequently, the relatively simple structure of Antarctic terrestrial ecosystems provides a well-constrained experimental extreme for assessing the dynamics and interactions of distinct biological components within and between trophic levels in: soils; permanently ice-covered lakes or ponds; intermittent streams; ice surfaces; and crypto-endolithic habitats (Greene and Friedman 1993, Priscu 1998, Lyons et al. 1997). In stark contrast to the Antarctic terrestrial ecosystem, the marine ecosystem is complex with more than 800 species of benthic molluscs alone (Arntz et al. 1997). Moreover, the Antarctic marine ecosystem is among the most productive in the ocean with diverse ecological interactions in planktonic, benthic and sea-ice habitats that give rise to exceptionally high standing stocks of fish, birds, marine mammals and other nektonic species (Smith 1990a,b) - many of which are commercially exploited with management under the 1980 *Convention on the Conservation of Antarctic Marine Living Resources* (Berkman 1992a).

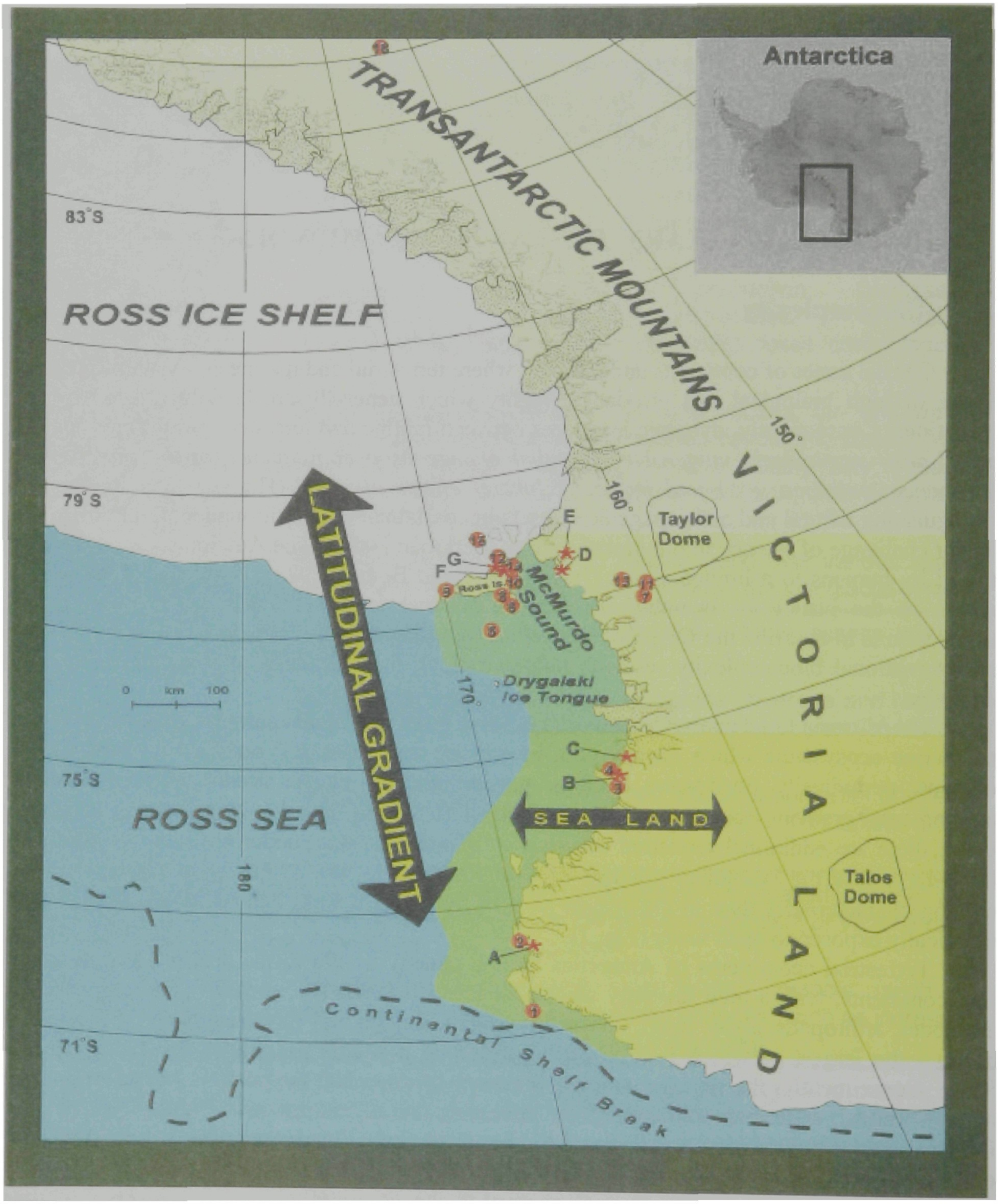


FIGURE 2: **Spatial context of the biocomplexity research initiative** along Victoria Land, Antarctica, from approximately 72°S to 86°S in the Ross Sea region. Principal relationships between "*dependent and associated ecosystems*" (as referenced in the *1991 Protocol on Environmental Protection to the Antarctic Treaty*) are described within the vertical and horizontal arrows. The principal research zones, which are recognized to have decreasing water vapor exchange between the ocean and land, from north to south are:

Open Water Zone	South of Cape Adare to the Drygalski Ice Tongue in the Terra Nova Bay region;
Fast Ice Zone	South of the Drygalski Ice Tongue to McMurdo Sound and the edge of the Ross Ice Shelf; and
Ice Shelf Zone	South of the Ross Ice Shelf edge along the flanks of the Transantarctic Mountains to the southern-most terrestrial ecosystems on Earth.

National research stations along with various protected areas and sites that have been adopted by the Antarctic Treaty System are listed below from north to south. Additional information on the protected areas and sites can be found on the attached CD-ROM of the *Antarctic Treaty Searchable Database: 1959-1999* or on the EvREsearch™ website (http://webhost.nvi.net/aspire).

Research Stations

A Cape Hallett (New Zealand and United States, abandoned)
B Gondwana (Germany, unoccupied)
C Terra Nova Station (Italy, summer only)
D Marble Point (United States, summer only)
E McMurdo (LTER) Long Term Ecological Research sites (United States, summer only)
F McMurdo Station (United States, year-round)
G Scott Base (New Zealand, year-round)

Protected Areas and Sites

(Specially Protected Areas -SPA / Sites of Special Scientific Interest - SSSI / Historic Sites - HS)

1 Cape Adare, (SPA 29, HS 22 and HS 23) 71°17'S, 170°15'E
2 Cape Hallett (SPA 7) 72°15'S, 170°10'E
3 Mt. Melbourne (SPA 22 and SSSI 24) 74°2o'S, 164°45'E
4 Inexpressible Island (HS 14) 74°54'S, 163°43'E
5 Beaufort Island (SPA 5) 76°58'S, 167°00'E
6 Cape Bird (SPA 20, SSSI 10) 77°14'S, 166°23'E
7 Barwick Valley (SSSI 3) 77°15'S, 161°00'E
8 Mt. Erebus (SPA 26, SSSI 11) 77°25'S, 167°30'E
9 Cape Crozier (SPA 6, SSSI 4, HS 21) 77°32'S, 169°18'E
10 Cape Royds (SPA 27, SSSI 1, HS 15) 77°33'S, 166°07'E
11 Linnaeus Terrace (SSSI 19) 77°35'S. 161°15'E
12 Cape Evans (SPA 25, HS 16 and HS 17) 77°38'S, 166°24'E
13 Canada Glacier (SSSI 12) 77°42'S, 163°00'E
14 McMurdo Station (SPA 28, SSSI 2, HS 18, HS 19, HS 20 and HS 54) 77°51'S, 166°38'E
15 White Island (SSSI 18) 78°S, 167°E
16 Amundsen's Cairn (HS 24) 85°11'S, 163°45'E

Around Antarctica, the solar radiation cycle (which varies from 24 hours of light to 24 hours of darkness) is a key environmental factor that controls the dynamics of both marine and terrestrial ecosystems by altering photosynthetic production. The seasonal cycle of sea-ice coverage (which varies from 3,000,000 to 20,000,000 km^2) is another pronounced physical factor which influences Antarctic ecosystem dynamics (Zwally et al. 1983, Lizotte and Arrigo 1998). Marine ecosystems also are influenced by icebergs that can scour the sea floor as well as alter current patterns and surface water masses (http://uwamrc.ssec.wisc.edu/amrc/iceberg.html). Sea-ice coverage, in the context of open water areas as moisture sources, play an important role in regional hydrological cycles (particularly the liquid phase) that strongly control the dynamics of Antarctic terrestrial ecosystems. Terrestrial and marine ecosystems across the Victoria Land coastal biome also are influenced by atmospheric temperature, pressure and humidity fields associated with glacial and orographic features on land as well as by currents and water masses associated with glacial and bathymetric features in the ocean (e.g. Drewry 1983, Vanney and Johnson 1985, Swithinbank 1988).

Suggestions about the coupling between marine and terrestrial environments along the latitudinal gradient of the Victoria Land coastal biome (Fig. 2) are revealed through stratigraphic records from marine and lake sediments as well as emerged beaches and lake chemical profiles which reflect ecosystem variability over millennial time scales (Doran et al. 1994, Berkman et al. 1998). For example, high resolution atmospheric records from the Taylor Dome ice core (Steig et al. 1998) along with deposits of marine plankton (Cunningham 1997), emerged macroinvertebrates (Berkman 1992b) and penguin rookeries (Baroni and Orombelli 1994) indicate that there was a distinct environmental shift around 6000 years ago which has affected ecosystem dynamics through the present along Victoria Land. It has been suggested that this mid-Holocene environmental shift along the Victoria Land Coast may be associated with the development of the Drygalski Ice Tongue (Berkman 1997), which influences the Terra Nova Bay polynya (Bromwich and Kurtz 1984) and reflects the dynamics of the East Antarctic Ice Sheet through the David Glacier. In a global context, there also were elevated temperatures and pronounced changes in the hydrological cycle during the mid-Holocene which have been recognized from the tropics to the Arctic (Thompson et al. 1995, Blunier et al. 1995) and may have been involved with onset of the El Niño Southern Oscillation (Sandwiess et al. 1996).

In an experimental context, Victoria Land provides a spatial gradient for evaluating environmental and ecosystem variability that otherwise only would be recognized only through time. Over short time scales, automatic weather stations and marine sensor arrays provide information for assessing the meteorological and oceanographic conditions (e.g. Jacobs 1985, Bromwich and Stearns 1994, Jacobs and Weiss 1998, Spezie and Manzella 1999) in relation to ecosystem dynamics (e.g. Lizotte and Arrigo 1998, Faranda et al. 2000) across the latitudinal gradient of the Victoria Land coastal biome during the 20th century. Monitoring of environmental parameters also has been conducted within regions, such as the Dry Valleys, where lake levels have been shown to be rising during the second half of the 20th century (Chinn 1993) as have global temperatures (Mann et al. 1998, Huang et al. 2000). Long-term monitoring also suggests that marine benthic populations in the Ross Sea region have been influenced by "interdecadal oceanographic climate shifts" (Dayton 1989) which may be related to global oscillations (Mann et al. 1995). Moreover, recent meteorological measurements and general circulation models are beginning to reveal teleconnections between the Victoria Land and intraseasonal oscillations associated with monsoons in the northern hemisphere (Hines et al. 2000).

Over smaller spatial and temporal scales, 'nanoclimate' measurements even have been made within endolithic habitats (McKay et al. 1993) to construct numerical models for predicting microbial ecosystem responses to environmental perturbations within the Victoria Land coastal biome (Nienow et al. 1988). Similarly, communities of epizooic species along with geochemical patterns across the growing margins of century-lived molluscs have been used for interpreting nearshore marine benthic zonation associated with glacial meltwater runoff over seasonal to decadal time scales in the McMurdo Dry Valleys (Berkman 1994a,b; Van Bloem 1996).

Interpretations about environmental and ecosystem coupling over diverse space and time scales are being enhanced by national programs (such as the McMurdo Dry Valleys - Long Term Ecological Research program or the West Antarctic Ice Sheet program in the United States) and international programs coordinated by the Scientific Committee on Antarctic Research (SCAR) and International Geosphere-Biosphere Program. These programs include geographic information systems for organizing interdisciplinary information (SCAR 1993, Hastings 1998) as well as approaches for integrating diverse datasets in the context of global research, education outreach, environmental protection and resource management (Alverson and Oldfield 1997, Berkman 2002, http://webhost.nvi.net/aspire). Conceptually, integration between the environmental and ecosystem components in the Antarctic coastal zone are represented in Figure 3.

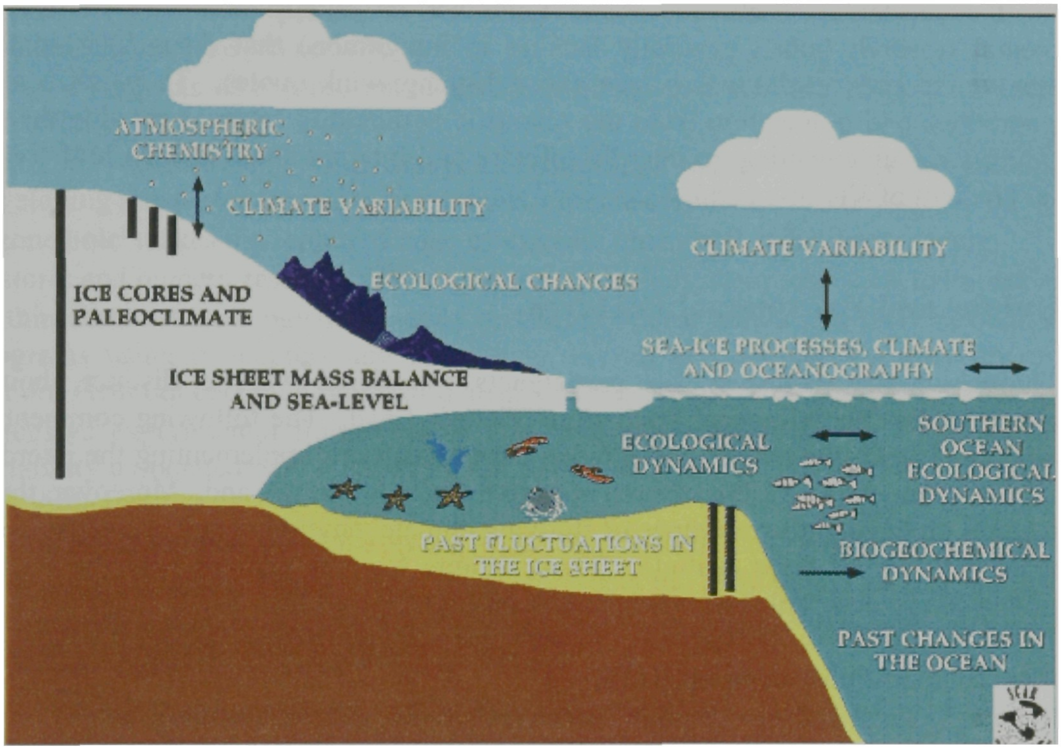


FIGURE 3: The network of international relevant global change research programs in the Antarctic and Southern Ocean (http://www.arncrc.utas.edu.au/scar/programmes.html), along with complementary datasets, under the auspices of the Scientific Committee on Antarctic Research (SCAR), International Geosphere and Biosphere Program (IGBP) and various national Antarctic programs are: **SEA ICE ZONE** Antarctic Ice Thickness Project (AnITRP); Antarctic Pack Ice Seals (APIS); Antarctic Sea-ice Processes and Climate (ASPeCt); International Antarctic Zone Program (iAnZone); International Programme for Antarctic Bouys (IPAB); **SOUTHERN OCEAN** International Marine Global Change Study (IMAGES); Joint Global Ocean Flux Study (SO-JGOFS); Southern Ocean - Global Ocean Ecosystems Dynamics (SO-GLOBEC); **GLOBAL CHANGE IN THE ANTARCTIC** Antarctic Geology and Paleoenvironments of the last 130 m.y. (ANTOSTRAT); Antarctic Neotectonics (ANTEC); Evolutionary Biology of Antarctic Organisms (EVOLANTA); International TransAntarctic Scientific Expedition (ITASE); Late Quaternary Sedimentary Record of Antarctic Ice Margin Evolution (ANTIME); Long-Term Ecological Research Program (McMurdo Dry Valleys LTER); Long-Term Ecological Research Program (Palmer Station LTER); Palaeoenvironments from Ice Cores (PICE); Climate and Cryosphere (CLIC); Climate Variability and Predictability (CLIVAR); and Regional Sensitivity to Climate Change in Antarctic Terrestrial Ecosystems (RiSCC).

Victoria Land, Antarctica, (Figs. 1 and 2) is ideally suited for a biocomplexity initiative because it reflects the "*interplay between life and its environment*" across:

- a latitudinal gradient that parallels the predominant trend of ice-sheet expansion and retreat associated with global climate changes;
- time in a region where habitats and ecosystems were re-established after the ice-sheet retreated at the end of the Last Glacial Maximum (around 13,000 years ago);
- ecosystems living at the liquid margin of life where climate changes have an amplified impact on the liquid-solid phases of water; and
- pristine and disturbed ecosystems responding to human impacts from local sources (such as research stations) and global sources (such as the ozone hole and global warming).

Moreover, the coastal zone along Victoria Land has an extensive history of ecosystem and environmental research (albeit generally lacking in integration) that dates back to the historic expeditions of the early 20th century (see above Borchgrevink quote). This rich background of research activities and momentum from the scientific community (Box 1) provide the framework for designing and implementing an interdisciplinary and international research initiative along the latitudinal gradient of Victoria Land.

1.2 Unique and Exceptional Features

Throughout the workshop, the participants considered what is distinct about studying biocomplexity across the latitudinal gradient of Victoria Land. The following comments represent the distillation of these discussions and provide the rationale for implementing the interdisciplinary latitudinal ecosystem (LAT-ECO) research initiative across Victoria Land. Moreover, the following unique features go beyond the relevance of studying climate, environmental and ecosystem research across more than 15° of polar latitude. These unique features address why the research along Victoria Land can be accomplished nowhere else on Earth.

- Most southern ecosystems on Earth;
- Relatively small anthropogenic influence (relatively pristine baseline);
- Extreme seasonality (24 hours of dark during winter / 24 hours of light during summer);
- Presence of ice shelves;
- Steep environmental gradient onshore/offshore;
- Steep biological gradient onshore-offshore;
- Antarctica has most limited terrestrial biodiversity of any continent (directly relates to ecosystem complexity, structure and function);
- Marine ecosystem dynamics "reset" when habitats opened after Last Glacial Maximum (~15ka);
- Latitudinal gradient of Victoria Land parallels the direction of ice-sheet retreat in the Ross Sea region after the Last Glacial Maximum;
- Excellent biotic preservation over millennia;
- Circumpolar ecosystem (modern species distributions, Late Quaternary fossils in raised beaches) and environmental dynamics (polar vortex, Antarctic Circumpolar Current) provide basis for comparisons around the entire continent;
- Extreme cold and aridity;

- High latitude systems show greater sensitivity to climate change than mid or low latitudes particularly during the summer, because small temperature changes will influence phase transitions of water between a liquid and a solid;
- Ability to integrate modern and historical records is unmatched elsewhere because of Holocene fossil assemblages (e.g. penguin rookeries and emerged beds of molluscs) can be integrated with extant analogs from the same species that can be experimental assessed in relation to modern environmental processes;
- Ice core records - highest resolution, continuous long-term records of climate change and/or regional environmental change which can be accessed over diverse time scales across greater than a 10° latitudinal gradient for immediately adjacent marine and terrestrial systems (records for reconstructing climate and chemistry of the atmosphere);
- Biocomplexity is strongly ice-controlled in relation to climate;
- Seasonality of primary production - with its consequent effects on ecosystem structure and function - is extreme (on or off);
- "Legacy" impacts of organic matter and habitat development are large, particularly in the terrestrial environment;
- “Extreme” environmental and ecosystem conditions reduce experimental ambiguities for developing adequate controls to test various climate-response hypotheses;
- 'Ozone hole' makes the region of zone of extreme ultraviolet radiation exposure;
- Historic and modern research stations for assessing ecosystem responses to human activities;
- Within demonstrated logistic capacity of United States, Italian and New Zealand Antarctic programs using helicopters and fixed-wing aircraft (*Twin Otters*) from primary national stations (without encumbering high-demand, expensive ice breakers or C-130 transport);
- Extensive experimental framework for assessing terrestrial ecosystem and environmental variability associated with the Long Term Ecological Research (LTER) site in the McMurdo Dry Valleys;
- Region of first human presence on the Antarctic continent (see Borchgrevink quote above);
- Within the Antarctic Treaty area, which represents the only region on Earth that has been continuously managed by *international cooperation* for *peaceful purposes only* based on the *freedom of scientific investigation.*

1.3 Climate, Environmental and Ecosystem Variability

The climate-driven dynamics and coupling of marine and terrestrial environments and ecosystems along Victoria Land are influenced strongly by different forms of ice. As the solid phase of water, ice represent aspects of the hydrological cycle that impact (Table 1):

- moisture exchanges;
- marine, freshwater and terrestrial ecosystem dynamics; and the
- basic availability of liquid water for terrestrial life.

TABLE 1: ICE ALONG VICTORIA LAND, ANTARCTICA

Habitats	Types of Ice
Marine	snow, sea ice, ice tongues, ice shelves, icebergs, meltwater
Freshwater	snow, lake ice, glaciers, permafrost, meltwater,
Terrestrial	snow, glaciers, permafrost, land ice, ice sheets, meltwater

Based on the workshop discussions and, in view of the workshop objectives (Table 1), principal topics for interdisciplinary collaboration in the Victoria Land research initiative were identified to be:

COLLABORATIVE TOPIC #1

Environmental thresholds across the latitudinal gradient of Victoria Land (e.g. continental shelf break, Drygalski Ice Tongue and Ross Ice Shelf) have a significant influence on the complexity of associated marine and terrestrial ecosystems.

COLLABORATIVE TOPIC #2

Across the latitudinal gradient of the Victoria Land system, ecological responses to land-air-sea interactions associated with climatic variability are amplified by ice (Table 2) and the availability of liquid water.

COLLABORATIVE TOPIC #3

Marine-terrestrial coupling across the Victoria Land system varies over time and space in relation to transfers of mass (sediments, salts, gases, water, nutrients, organic matter and organisms), momentum (currents and winds) and energy (latent heat).

In effect, collaborative topics #1 and #2 provide alternative hypotheses that could be tested and modeled to interpret ecosystem and environmental variability along the latitudinal gradient of Victoria Land (Fig. 4). Collaborative topic #3 further identifies the interdisciplinary context for analyzing the environmental systems that affect habitat and ecosystem dynamics across Victoria Land. Together, this climate-driven framework for the interdisciplinary collaborations in the Victoria Land biocomplexity research initiative is conceptualized in Figure 5.

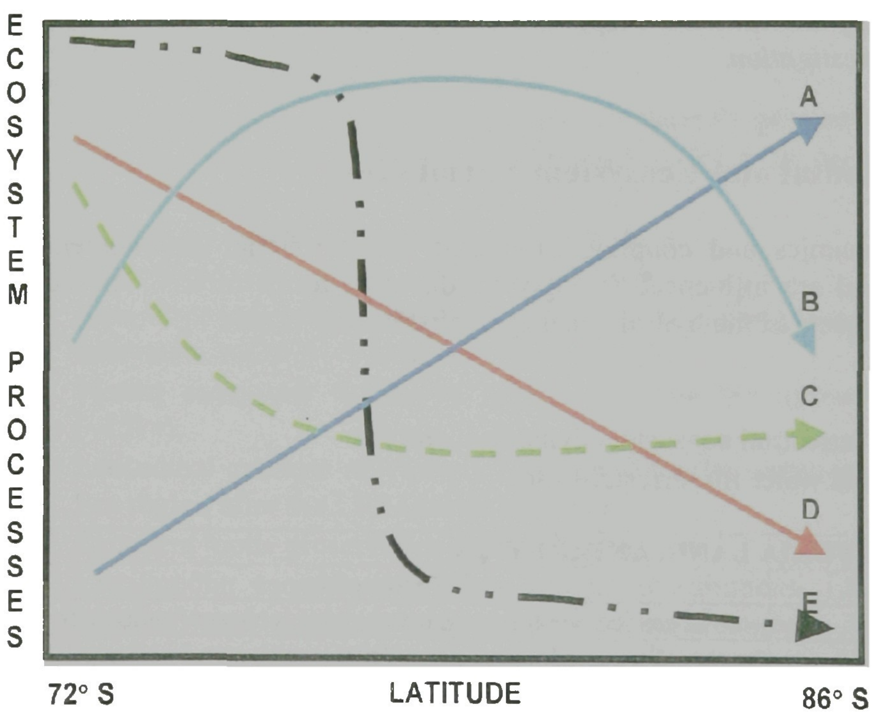


FIGURE 4: Alternative explanations for the variability in comparable ecosystem processes in marine, freshwater and terrestrial habitats (Table 1) across the latitudinal gradient of Victoria Land, Antarctica: **A** and **D** (linear ecosystem changes associated with environmental phenomena such as solar radiation and photo-periods) and **B, C and E** (non-linear ecosystem changes associated with environmental phenomena such as the number of freeze-thaw cycles and ice-tongue thresholds). Modified from Peterson and Howard-Williams (2001).

FIGURE 5

LATITUDINAL ECOSYSTEM RESPONSES TO CLIMATE ACROSS VICTORIA LAND, ANTARCTICA

OVERARCHING CLIMATE HYPOTHESIS

CLIMATE-DRIVEN DIVERSITY OF PHYSICAL SYSTEMS INFLUENCES THE STRUCTURE AND FUNCTION OF BIOLOGICAL SYSTEMS ACROSS THE EARTH

↓

OVERARCHING HIGH-LATITUDE HYPOTHESIS

ICE-DRIVEN DYNAMICS CONTROL THE STRUCTURE AND FUNCTION OF BIOLOGICAL SYSTEMS AT HIGH LATITUDES

↓

RESEARCH FOCUS

ANTARCTIC ECOSYSTEM RESPONSES TO CLIMATIC AND ENVIRONMENTAL VARIABILITY

↓

RESEARCH LOCALITY

LATITUDINAL GRADIENT
VICTORIA LAND, ANTARCTICA
(72°S - 86°S)

↓

PRINCIPAL ENVIRONMENTAL FORCING

MASS BALANCE OF MARINE, FRESHWATER AND TERRESTRIAL ICE (Table 1)

↓

ECOSYSTEM RESPONSES

TERRESTRIAL ZONE	COASTAL TRANSITION	MARINE ZONE

← SPATIAL AND TEMPORAL LINKAGES →

BACKGROUND RESEARCH (abstract authors in bold)

2.1 Climate, Environmental And Ecosystem Dynamics

__Space and Time Scales__ Earth contains land, air, water and life phenomena with rhythms of nested natural variability that are connected over time and space (Fig. 6; **Costa**; **Hobbie**; **Jeffries et al.**; **Licht**). Understanding the relative temporal and spatial dimensions of the ecosystem and environmental phenomena along the Victoria Land latitudinal gradient are central to defining and accomplishing the objectives of this research initiative.

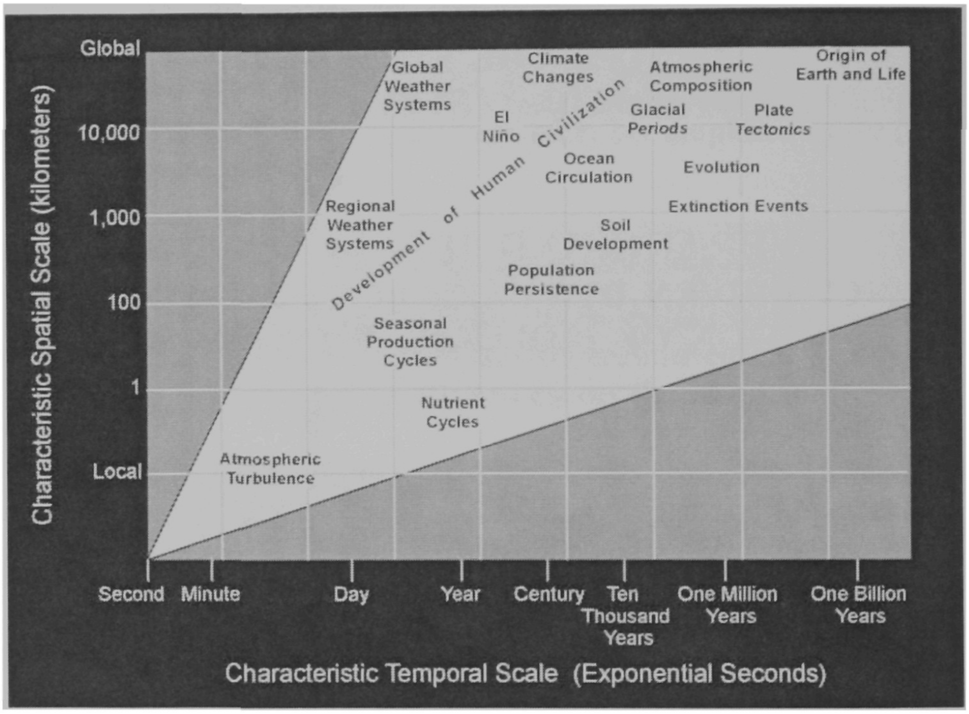


FIGURE 6: Time and space scales of phenomena in the Earth system. From Berkman (2002).

For the purpose of this research, environmental and ecosystem coupling will be considered after the Last Glacial Maximum in the Ross Sea region (around 13,000 years ago) when the West Antarctic Ice Sheet (WAIS) retreated and progressively opened habitats southward along the coast of Victoria Land. This continental region is occupied by ice streams, which are anomalously fast-moving regions of the ice sheet which can contribute to the rapid disintegration of the ice sheet itself (**Conway**). Past retreat of these ice streams and the grounding line of the marine-based West Antarctic Ice Sheet in the Ross Sea region paralleled the coast of Victoria Land after the Last Glacial Maximum (Fig. 7) - reflecting the direct connections of this Antarctic region to global climate and sea level.

The corresponding history of ecosystem development along Victoria Land, which only became possible after habitats were no longer covered by ice sheets, is reflected by Holocene deposits in marine sediments (**Licht; Powell; Scherer et al.**), emerged beaches (**Conway**), terrestrial lakes (**Doran**), terrestrial ecosystems (**Lyons; Wall**) penguin rookeries (**Costa; Emslie**) and ice cores (**Steig; Waddington**). In particular, beginning around 6000 years ago, the Ross Sea region entered a new phase in ecosystem dynamics in conjunction with global climate conditions and local environmental changes in sea-ice coverage. These ecosystem changes are reflected by the geochemistry of the ice sheet in the terrestrial zone, occurrence of marine species in the coastal transition zone and deposition of phytoplankton species in the marine zone along Victoria Land

(Figs. 8a-c). This period during the Holocene, which represents the current interglacial climate phase that began 10,000 years ago, is most relevant to understanding ecosystem dynamics today.

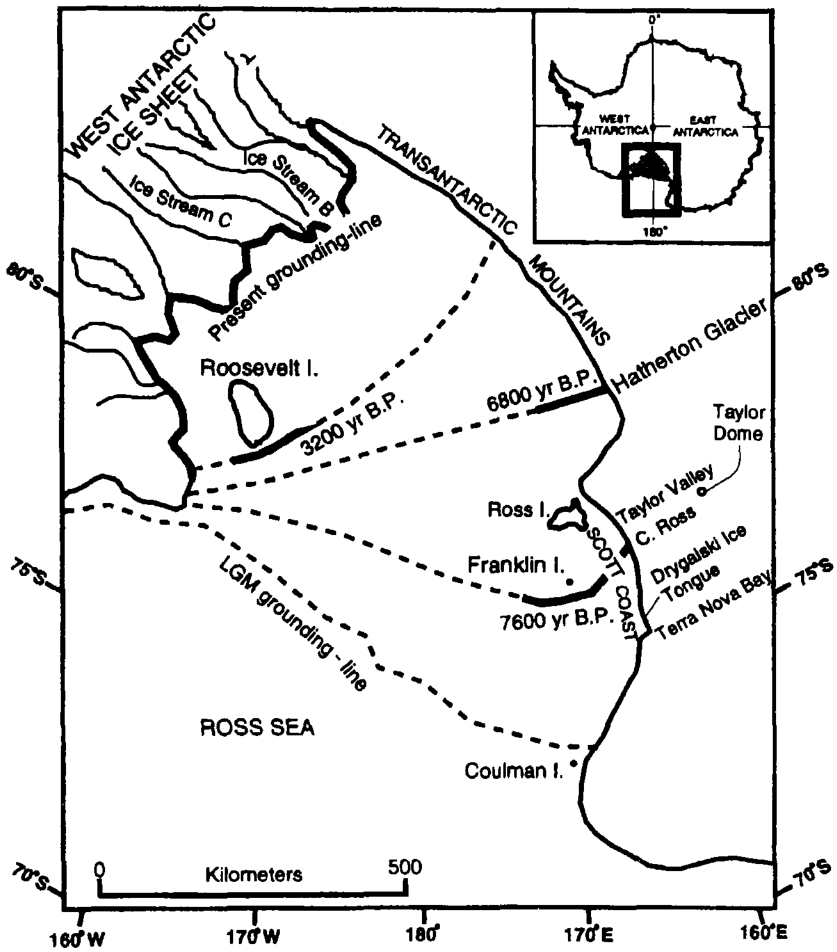


FIGURE 7: Holocene grounding-line recession of the ice-sheet in the Ross Sea Embayment after the Last Glacial Maximum (**Conway, Licht**). Adapted from Conway et al. (1999)

In addition to long-term millennial variability (Figs. 7 and 8), short-term decadal, annual and seasonal changes also have been identified in marine and terrestrial ecosystems along Victoria Land. In particular, measurements from the 105 km^2 area of the Long Term Ecological Research (LTER) program in the McMurdo Dry Valleys have been instructive in evaluating the variability in modern terrestrial ecosystem productivity associated with lake levels, stream flow, snowfall, melting and the local meteorology in the coastal zone of southwestern McMurdo Sound (**Doran**; **Lyons**; **Moorhead**; **Priscu**). Terrestrial ecosystem variability in the McMurdo Dry Valleys LTER, including the distribution and abundances of species, also has been related to the "legacy" of old carbon remaining from past habitats and environmental conditions after the Last Glacial Maximum (**Wall**). Recent research also demonstrates that intra-seasonal variability in adjacent nearshore marine environments is recorded over decades in the shells of the century-lived Antarctic scallop, *Adamussium colbecki* (**Lohmann et al.**). These short-term variations in the coastal zone along Victoria Land represent the research challenges for understanding the:

- Coupling within and between marine and terrestrial ecosystems and environments;
- Legacy effects of past environments and ecosystems in relation to the distributions, abundances and dynamics of biological assemblages in modern marine and terrestrial habitats;

- Nested variability of marine and terrestrial ecosystems and environments over different time and space scales; and
- Climate-driven dynamics of marine and terrestrial ecosystems and environments as sentinels of Earth system variability.

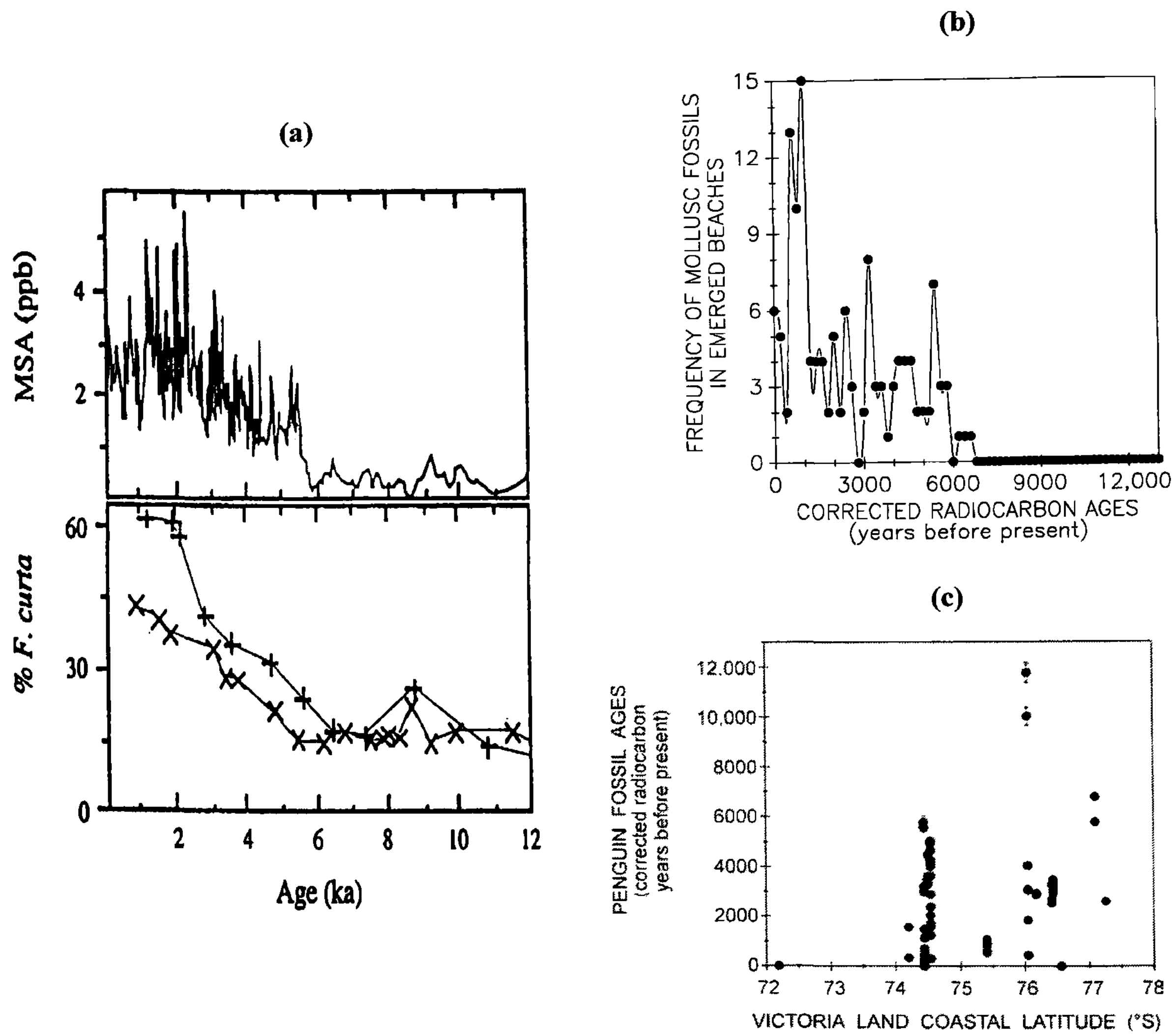


FIGURE 8: Temporal context of the biocomplexity research initiative showing an environmental transition along Victoria Land during the mid-Holocene warming period around 6000 years ago, when the global climate system began stabilizing toward its present condition following the Last Glacial Maximum (nearly 13,000 years ago around Antarctica). (**a**) Taylor Dome ice core transition identified in relation to methanesulfonic acid (MSA) concentrations associated with sea-ice production. Percentages of the sea-ice diatom *Fragilariopsis curta* in Ross Sea sediment deposits based on Cunningham (1997). From Steig et al. (1998). **(b)** Emergence of nearshore marine molluscs in raised beaches along Victoria Land, from Terra Nova Bay to southwestern McMurdo Sound. Modified from Berkman et al. (1998). **(c)** Occupation of Adélie penguin (*Pygoscelis adeliae*) rookeries in relation to latitude along the Victoria Land Coast during the last 13,000 years. Persistence of the Adélie penguin rookeries in the vicinity of the Drygalski Ice Tongue and Terra Nova Bay polynya associated with access to open water. Based on data from Baroni and Orombelli (1994) as adapted by Berkman (1997).

Oceanography

The ocean responds to climate variability over longer time scales than the atmosphere, depending on the location on the Earth and depth in the sea. The bathymetric profile along the coast of Victoria Land (Fig. 9) provides the physical framework for identifying:

- deeper basins for collecting well-preserved marine sedimentary stratigraphies;
- troughs for interpreting glacial and ice-sheet flow patterns; and
- locations associated with the origin and dynamics of water-masses (Fig. 10).

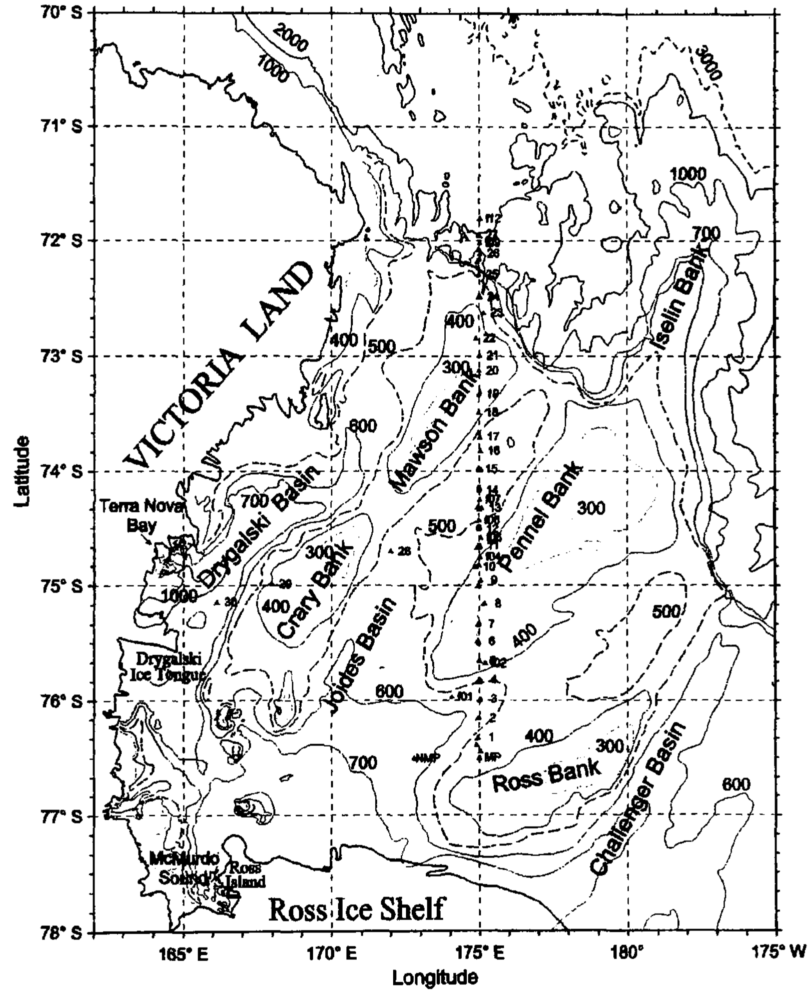


FIGURE 9: Bathymetric profile along the Victoria Land coast in the Ross Sea. From the Ross Sea Marginal Ice Zone Experiment (ROSSMIZE) cruise in 1994 **(Costa)**.

For example, southward intrusion of Modified Circumpolar Deep Water (MCDW) and development of Antarctic Surface Water (AASW) in the Ross Sea coincide in the vicinity of the Drygalski Ice Tongue overlying the Drygalski Trough, around 74°S. These water masses both have surface temperatures warmer than +1°C during the summer in the Terra Nova Bay region, in contrast to the sub-zero maximum sea surface temperatures near the Ross Ice Shelf in McMurdo Sound **(Bergamasco et al.)**. In addition, evolution of water masses in the Ross Sea is associated with:

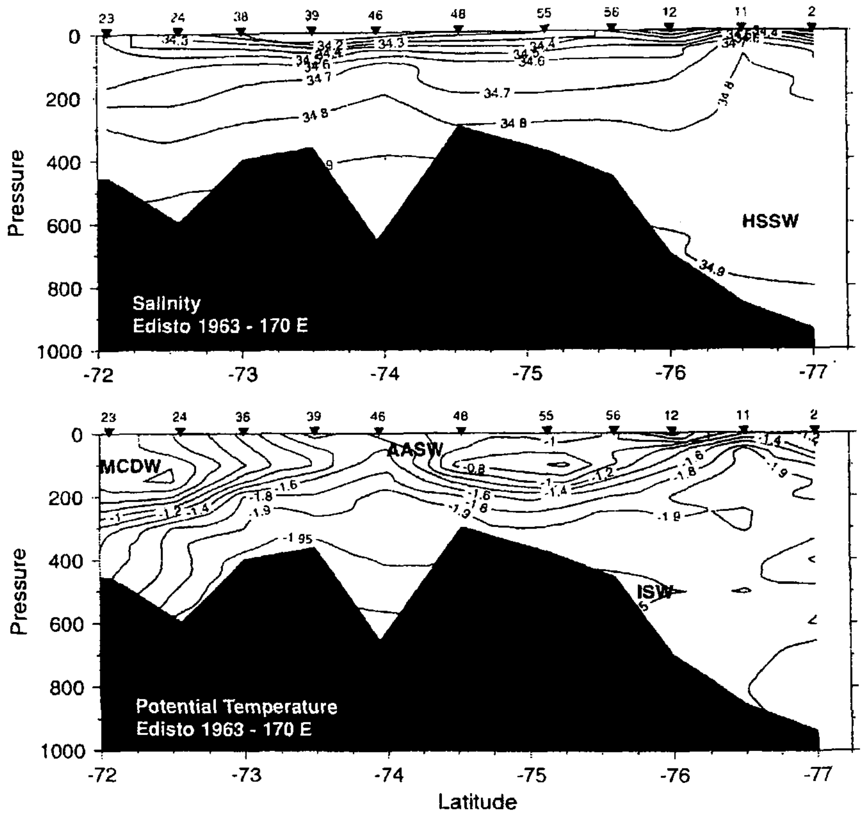
- regional and global atmospheric processes;
- sea-ice, ice-shelf, ice-tongue and glacial processes; and

- hydrographic exchanges with the deep sea.

Together, these oceanographic processes influence the spatial and temporal patterns of community production (**Cattaneo-Vietti; Eastman; W. Smith**) as well as:

- marine species' distributions and abundances;
- marine species' forms and functions; and
- trophic dynamics and productivity 'hot spots.'

FIGURE 10: Oceanographic transect parallel to Victoria Land, showing salinities and potential temperatures as well as bathymetries in the Ross Sea, across the latitudinal gradient from 72°S southward to 77°S along the 170°E meridian. Distribution of water masses are identified for: Antarctic Surface Water (AASW), High Salinity Shelf Water (HSSW), Ice Shelf Water (ISW) and Modified Circumpolar Deep Water (MCDW). From Jacobs and Guilivi (1999).



<u>**Sea Ice**</u> Sea ice influences the dynamics of marine and terrestrial ecosystems as one of the most integrated natural phenomena in the Antarctic region (**Jeffries et al.**). Because of diverse hydrological, glaciological, oceanographic and meteorological feedbacks, there also are numerous gradients and thresholds in the types and distributions of sea ice along Victoria Land today. For example, from west McMurdo Sound to the Drygalski Ice Tongue there is landfast sea ice that is associated with supercooled water moving northward from under the Ross Ice Shelf (Fig. 11). In contrast, annual sea ice occurs in east McMurdo Sound and north of the Drygalski Ice Tongue, which also influences the open-water region of the Terra Nova Bay polynya.

As in the past (Figs. 8a-c), sea-ice extent appears to be related to climate conditions. For example, in the Antarctic Peninsula region where there has been significant warming during the last half century, sea-ice extent has decreased as air temperatures have warmed (**R. Smith**). With this initiative, understanding the dynamics of ecosystems associated with the sea ice along Victoria Land (**Fritsen; Jeffries et al.; Lizotte**) requires a much more thorough understanding of the:

- Controls on the extent, thickness and modes of formation of landfast sea ice, their role in determining landfast ice ecosystem structure and productivity, and the contribution of landfast ice ecosystems to Ross Sea productivity;
- Spatial and long term variability in the seasonal evolution of pack ice drift and deformation, ice thickness and snow depth, and ice formation and thickening processes on the continental shelf and the deep ocean;
- The role of pack ice geophysical processes in shaping sea ice microbial community structure and productivity, phytoplankton blooms and marine productivity, and marine mammal ecology;
- Magnitude and variability of interactions and exchanges between nearshore and offshore regions. For example, sea ice is associated with: **(1)** controls on polynya dynamics (opening/closing), the magnitude of polynya ice production and export, and its contribution to pack ice mass; **(2)** the nature of the coupling, if any, between the Terra Nova Bay, Ross Sea and McMurdo polynyas; and **(3)** the role of polynyas in ice and ocean ecology and productivity;
- The role of the marine environment in determining terrestrial physical and biological interactions and processes. For example, sea ice and ocean effects on continental precipitation and temperature variability, and the impact on terrestrial ecosystems and productivity.
- Marine sediments, ice cores and other proxies of marine palaeo-environmental (physical and biological) variability and change: site selection, acquisition, analysis and interpretation.

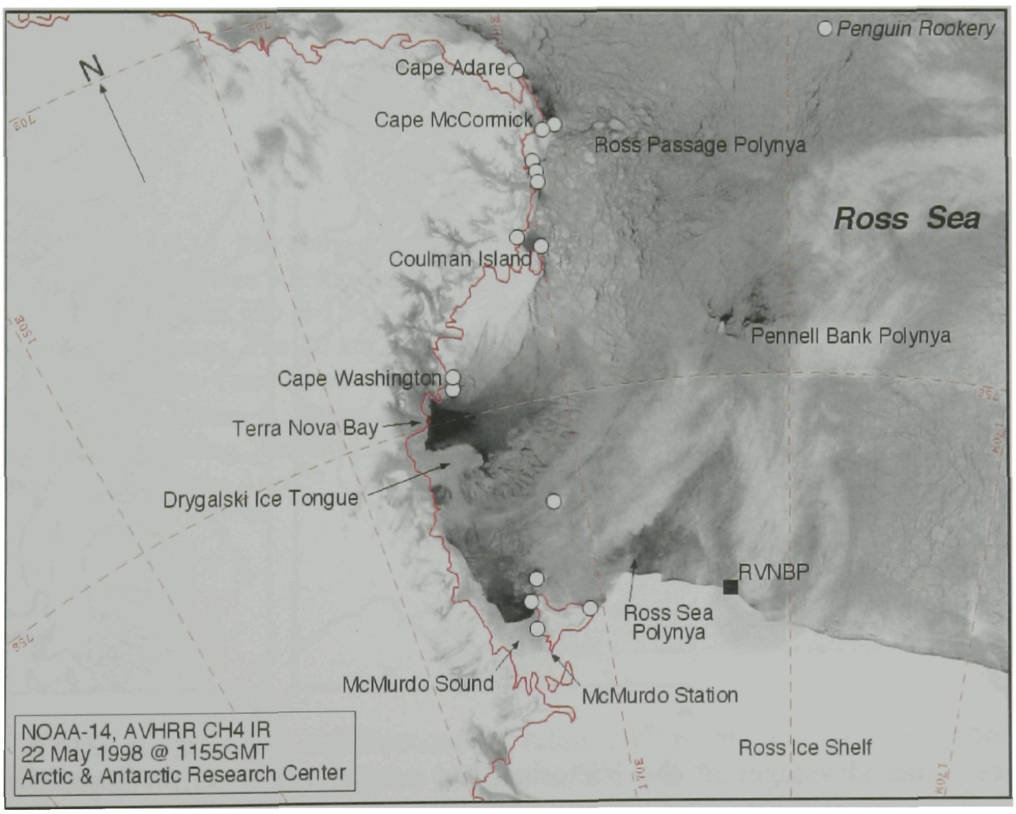


FIGURE 11: NOAA AVHRR satellite image of the southwestern Ross Sea showing landfast sea ice, pack ice and polynyas on 22 May 1998. Adélie (*Pygoscelis adeliae*) and Emperor (*Apenodytes forsteri*) penguin rookeries are shown as circles. From Jeffries et al. (**abstract**).

Meteorology Dynamics of terrestrial and marine ecosystems along Victoria Land are directly associated with meteorological events and processes (**Bromwich and Monaghan**). Most notably, primary production cycles and ecosystem dynamics are closely coupled with the seasonal light regime, which progresses from 24 hours of darkness to 24 hours of daylight (Table 2).

TABLE 2. Radiation at the top of the atmosphere (in MJ m^{-2} day^{-1}) as a function of latitude and time of year between 60°S and 90°S. Adapted from Vincent (1988).

	Month												Total
Latitude	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**(MJm^{-2} y^{-1})**
60°S	**42**	**31**	**19**	**11**	**4**	**2**	**3**	**8**	**18**	**27**	**38**	**44**	**7417**
70°S	**42**	**28**	**13**	**5**	**1**	**-**	**-**	**3**	**13**	**22**	**37**	**45**	**6174**
80°S	**44**	**26**	**6**	**-**	**-**	**-**	**-**	**-**	**6**	**18**	**38**	**47**	**5592**
90°S	**44**	**26**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**18**	**39**	**48**	**5411**

Glacier-ocean-atmosphere interactions also influence meteorological conditions along Victoria Land, as exemplified by the presence of the Terra Nova Bay polynya formed by the katabatic winds blowing down the David Glacier across the Drygalski Ice Tongue into the Ross Sea. In addition, there are geomorphological interactions, in particular the Transantarctic Mountains that block the trajectories of barrier winds and cyclones flowing eastward across the Ross Sea and divert the airflows northward parallel to the Victoria Land Coast.

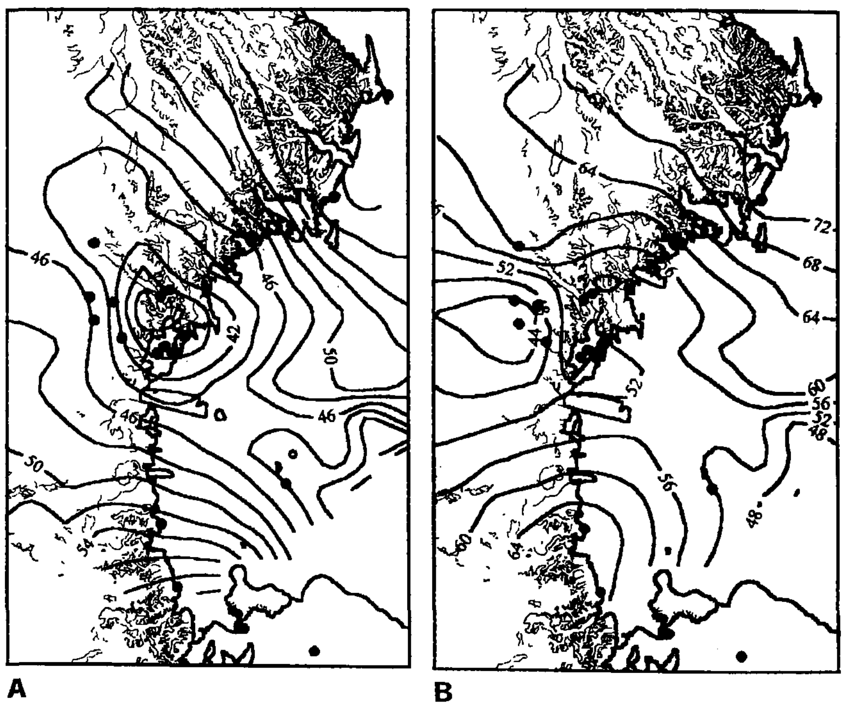


FIGURE 12: Maps of relative humidity (in percent) measured from Automatic Weather Stations along Victoria Land during the **(a)** winter and **(b)** summer. From Colacino et al. (2000).

One of the advantages of the Victoria Land coastal region is the broad distribution of Automatic Weather Stations (**Pelligrini**) as well as rawinsonde, Automatic Geophysical Observatories and satellite pass receiver sites (**Bromwich and Monaghan**) for:

- measuring the regional meteorological conditions

- modeling the atmospheric coupling between Antarctica and lower latitudes in relation to global phenomena, such as the El Niño Southern Oscillation;
- interpreting glacial accumulation and ice-core records;
- identifying environmental and ecosystem transition zones; and
- interpreting coupling between marine and terrestrial environments.

An example of the meteorological data that are available for assessing environmental linkages and feedback along Victoria Land is shown in Figure 12 with the divergence of relative humidity contours in the vicinity of the Dryglaski Ice Tongue and Terra Nova Bay polynya.

- What is the feedback between the ice tongues, polynyas, moisture transport and glacial accumulation?
- How will global warming influence the accumulation of glaciers and the dynamics of their ice-tongue extensions into the marine environment?

<u>Glaciology</u> The extent and flow of glaciers are influenced by their underlying topography and substrata as well as the atmospheric process that contribute to their accumulation and ablation (**Conway**). On the large end of the glacial spectrum, the Ross Sea region is influenced by both the marine-based West Antarctic Ice Sheet (WAIS) and land-based East Antarctic Ice Sheet (EAIS). Together, the ice volume of these two ice sheets has enough frozen water to raise global sea level on the order of 60 meters if they completely melted.

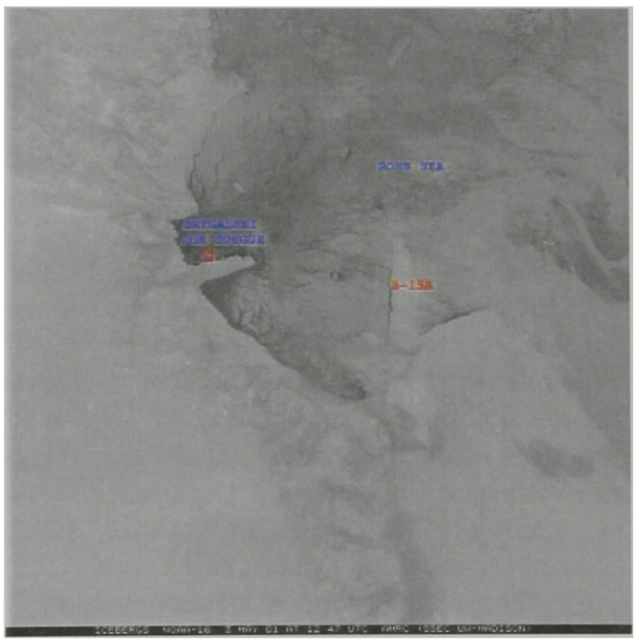


FIGURE 13: Iceberg B-15 that calved from the Ross Ice Shelf in March 2000 was 300 km in length by 40 km in width before it broke into B-15A (shown in red) and other smaller icebergs. The 80 km Drygalski Ice Tongue (in blue) in the Terra Nova Bay region along the Victoria Land Coast is shown for scale. ATSR (Along Track Scanning Radiometer) satellite image from the European Space Agency.

The WAIS, in particular, is influenced by relatively fast moving ice streams that may have the potential to rapidly draw down massive volumes of ice into the ocean over centuries. Currently, the WAIS ice streams are buttressed from surging into the ocean by the massive Ross Ice Shelf, which periodically calves giant tabular icebergs from its nearly 700,000 km^2 area (Fig. 13). These icebergs can alter the salinity and density of seawater in their immediate vicinity, which will further modify local polynyas as well as sea-ice coverage and thickness. In addition, icebergs can influence current trajectories as well as the ecology of coastal ecosystems when they are grounded.

Over millennial time scales, southward retreat of the WAIS is reflected in both the marine and terrestrial environments. Marine sedimentary deposits show the retreat of the WAIS grounding line since the Last Glacial Maximum (Fig. 7). Retreat of the WAIS also is illustrated by the relative emergence profiles of beaches along Victoria Land which are isostatically rebounding from the diminished overburden of the ice sheets (Fig. 14).

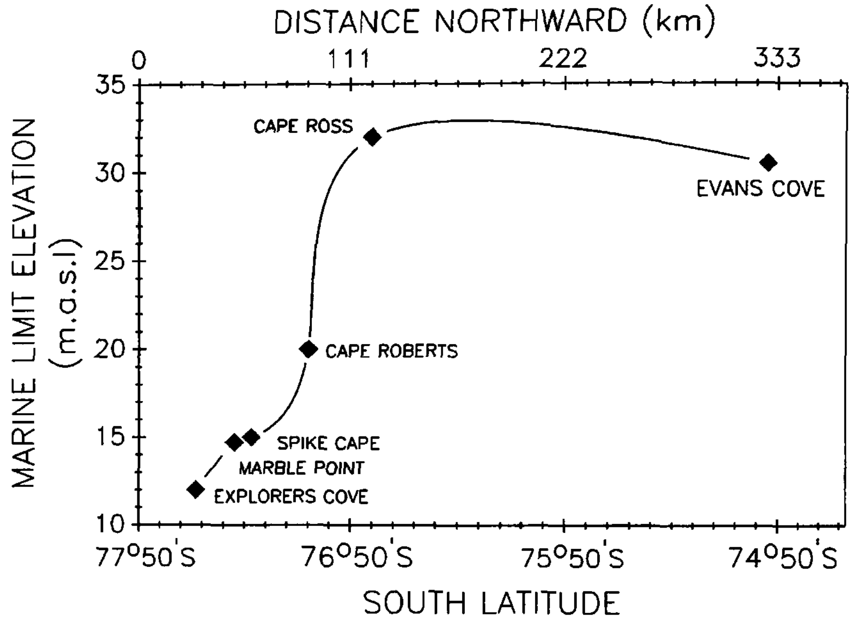


FIGURE 14: Relative emergence profiles along the coast of Victoria Land showing the latitudinal pattern of Holocene marine-limit elevations (in meters above sea level) that have been preserved in raised beaches (Berkman unpublished).

There also are glaciers that are connected to the EAIS that reflect large scale atmospheric forcing. These outlet glaciers include the David Glacier that flows into the Drygalski Ice Tongue in the Terra Nova Bay region as well as the Mackay Glacier that flows into Granite Harbor in west McMurdo Sound (**Powell**). Ice tongues are like piano keys that advance and retreat in concert with the larger climate system, with dynamic feedbacks associated with oceanographic and atmospheric phenomena (Figs. 7, 9, 10, 11 and 12). Moreover, along the Victoria Land Coast, there are piedmont glaciers that are fed by local moisture sources, such as the Wilson Piedmont Glacier in west McMurdo Sound. There also are numerous alpine glaciers along Victoria Land in between the coast and the EAIS. These glaciers affect the local biota by providing key liquid water sources during the short summer melt season. The areas close to the glacier termini can host relatively rich biological communities. As they advance or retreat in response to climate, the alpine glaciers also destroy or create, respectively, these special habitat zones. Interactions among these glacial features may influence environmental transition zones as illustrated in the vicinity of Granite Harbor (Fig. 14), where there is a ten-meter elevation change of the preserved marine limits between Cape Ross to the north and Cape Roberts to the south.

The cold dry polar environment of Victoria Land is excellent for preserving detailed paleoclimate proxies in ice cores. Records of precipitation, temperature, windiness and atmospheric circulation can be recovered from sites in the Transantarctic Mountains and from the polar plateau For example, the Taylor Dome ice core (Fig. 8a) covers that last 150,000 years, while records from Newell Glacier and the Dominion Range cover shorter periods. The proximity of these extensive, high-resolution, high-quality paleo-records as well as ongoing ice-core programs (such as the International TransAntarctic Scientific Expedition - ITASE) adjacent to a biocomplexity site is unprecedented (**Mayewski; Steig; Waddington**).

- Where are the environmental transition zones along Victoria Land and how are they linked to glacier extent, meltwater patterns, surficial deposits and erosional surfaces?
- How are the glacier extent and hydrology patterns along Victoria Land influenced by atmospheric phenomena associated with local to regional meteorology as well as the global climate?
- How do changes in the glacial systems along Victoria Land impact adjacent marine and terrestrial ecosystems?
- What are the response times and feedbacks of different types of glacial systems (e.g. ice sheets, ice streams, piedmont glaciers, outlet glaciers, alpine glaciers or ice tongues) along Victoria Land to atmospheric and meteorological changes?
- How can geomorphological and sedimentary records be used to study changes in the marine and terrestrial ecosystems along Victoria Land?
- What can paleoclimate records from ice cores tell us about the spatial patterns and temporal variability of ecosystems along Victoria Land since the Last Glacial Maximum?
- How can modern glaciological processes and impacts be used as analogs for interpreting past geomorphological and sedimentary records that are preserved along Victoria Land?

2.2 Ecosystem And Environmental Zones

Marine Zone: Marine ecosystems along Victoria Land are known to vary across the latitudinal gradient in terms of maximum sea-surface temperatures; sea-ice extent; productivity and species assemblages. Oceanographic surveys indicate that maximum sea-surface temperatures are greater than 2°C north of the Drygalski Ice Tongue but are less than 0°C in McMurdo Sound to the south (Fig. 10). Sea-ice along the coast of Victoria Land also varies with current patterns, harbours and embayments, katabatic wind regimes and ice-tongues (Fig. 11). Generally, in west McMurdo Sound, there is multi-year sea ice which can increase in thickness to nearly 6 meters depth over periods longer than six years. On the other end of the extreme are open-water areas, like the Terra Nova Bay and Ross Sea polynyas. Responding to their environments, marine species along Victoria Land are known to vary in terms of their:

- distributions and abundances
- life history patterns, morphologies and energetics; and
- biochemical and physiological adaptations.

In addition to assessing marine biological responses to natural environmental variability along Victoria Land, there are opportunities for assessing local to global impacts from human activities (**Focardi et al.**):

- What is the biomagnification of pollutants in marine webs along Victoria Land in relation to local and global sources?
- Can the latitudinal gradient approach be used to assess the bioaccumulation of global contaminants?
- What are the important biomarkers within species for assessing local and remote pollution impacts in habitats along Victoria Land?

At the base of the marine food-chain, there are open-water diatom assemblages which are distinct from species that more commonly occur in regions covered by sea ice. These phytoplankton species also are preserved in the sediments and provide records of paleoenvironmental conditions along Victoria Land (Fig. 8a).

Most of our undertstanding about benthic marine communities along Victoria Land (e.g. Fig. 15) is limited in geographic scope to McMurdo Sound (which has been extensively surveyed by the United States and New Zealand Antarctic programs) and Terra Nova Bay (which has been extensively surveyed by the Programma Nazionale di Richeche in Antartide). It is known that benthic algae are luxuriant in the Terra Nova Bay region with vibrant stands at depths less than 20 meters, whereas they are virtually absent in most areas in west McMurdo Sound (**Chiantore et al**.). These benthic algae also include extensive coverage of corraline red algae on virtually all rocks in shallow-water in the Terra Nova Bay region while they are rare in McMurdo Sound. This distribution of calcareous benthic algae, in part, is related to the warmer sea-surface temperatures and decreased solubility of calcium carbonate in the Terra Nova Bay region.

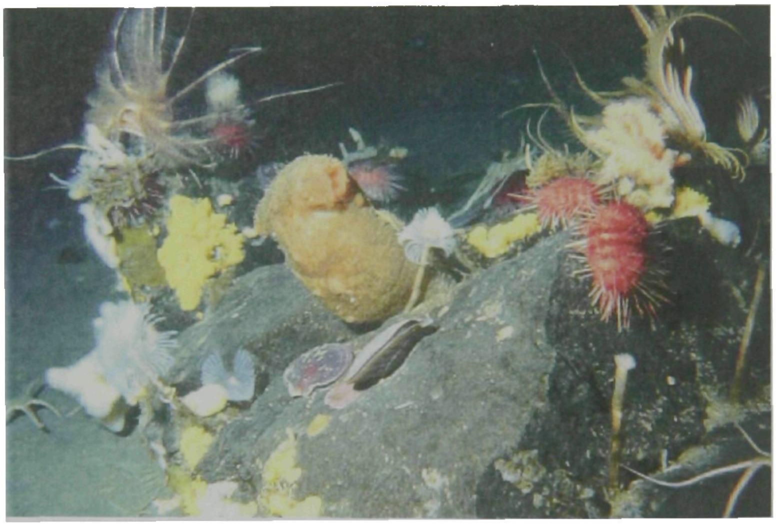


FIGURE 15: Marine benthic species diversity in west McMurdo Sound, Antarctica (P.A. Berkman).

Among the benthic macroinvertebrates, species like the circum-Antarctic scallop (A*damussium colbecki*) provide experimental templates for comparing and contrasting environmental conditions between habitats (**Chiantore**; **Kim**; **Norkko et al.**). For example, like the distribution of corraline algae, *Adamussium* shells are significantly thicker in Terra Nova Bay than in McMurdo Sound with stable isotope signatures that further reflect the relative seawater temperatures and production levels between these regions (Fig. 16). There also are indications that *Adamussium* are releasing their gametes later in the austral summer and producing larger planktonic larvae in Terra Nova Bay than in McMurdo Sound (**Cattaneo-Vietti**; **Chiantore**).

At the upper trophic levels, fish species have been an important research focus along Victoria Land because of their accessibility and utility for assessing adaptive responses to environmental variability. Fish trawls have provided important baselines for characterizing marine community structures, diversities and distributions in relation to oceanographic conditions along Victoria Land with additional sites proposed from south to north (**Eastman**):

- Erebus Basin as a baseline for high-latitude deep-water locality;
- Sponge beds as sites of topographic and trophic complexity leading to high fish diversity;
- Crary or Mawson banks as sites of high diversity surrounded by deep water areas;
- Drygalski Trough as site of deepest and largest inner shelf depression in the Ross Sea;

- Cape Adare as a continental shelf transition zone; and
- Iselin Seamount as a site of faunal transition and dispersal into the Ross Sea.

Antarctic fish are unique among vertebrates as the only fauna to have species (Family Channichthyidae) without hemoglobin in their blood. Glycoprotein antifreezes as well as other biochemical and physiological adaptations, reflect additional adaptive responses at the extreme of cold seawater temperatures (**di Prisco**; **Sidell**). Relatively subtle increases in seawater temperatures could alter the physiological and biochemical processes among Antarctic fish faunas. Moreover, seawater temperature increases could lead to the incursion of species not generally found in the high latitudes that would further alter fish community compositions, interactions and dynamics.

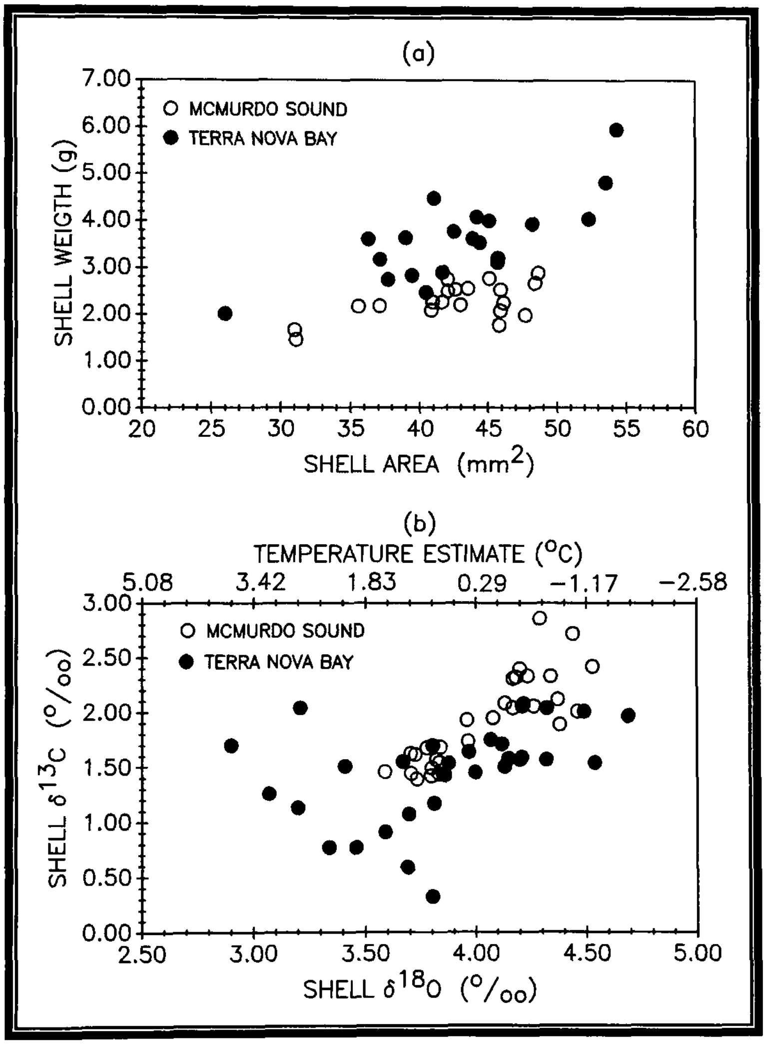


FIGURE 16: Comparisons of Antarctic scallop (*Adamussium colbecki*) shell geochemistry from nearshore marine environments across the latitudinal gradient of Victoria Land (Fig. 2), in Terra Nova Bay and west McMurdo Sound. **(a)** Shells precipitated in McMurdo Sound, which has maximum sea surface temperatures below 0°C (Fig. 8), are significantly thinner ($F=7.64$, d.f. 2,61 $p<0.001$) than those precipitated in Terra Nova Bay, which has maximum sea surface temperatures around 2°C (Fig. 10). **(b)** Stable carbon and oxygen isotope ratios in shells reflect significantly warmer and more productive seawater conditions ($F=22.27$, d.f. 2,37, $p<0.001$) in Terra Nova Bay than in McMurdo Sound. Estimated temperatures do not account for meltwater contributions. From Berkman (unpublished).

Environmental conditions and suitable habitats similarly influence the distribution of avian faunas in the Ross Sea region (Fig. 17). For example, the distribution of penguin rookeries is closely coupled with sea-ice coverage because of their required access to open-water areas where they forage. Today, the largest Adélie penguin (*Pygoscelis adelie*) rookery in Antarctica occurs in Cape Adare with most southern rookeries along Victoria Land in the vicinity east McMurdo Sound (Fig. 11), where there is direct coastal access to open water each year. Guano deposits from these penguin rookeries (Fig. 18), which include remains of their prey as well as organic materials for radiocarbon dating (**Emslie**), provide information for assessing their past distributions and paleo-environmental conditions (Fig. 8c).

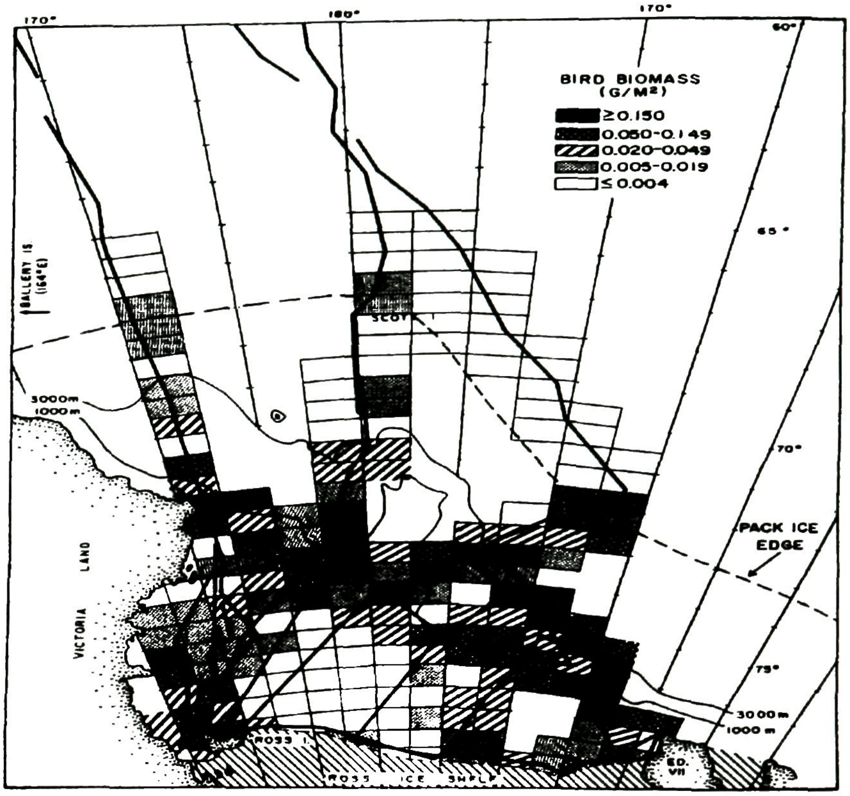


FIGURE 17: Distribution of bird biomasses in the Ross Sea region. From Ainley (1985).

FIGURE 18: Rookery of Adélie penguins (*Pygoscelis adeliae*) that has persisted since the mid-Holocene (Fig. 6c) in Adelie Cove in the Terra Nova Bay region (P.A. Berkman).

Among the marine mammals, the southern-most seal species on Earth is the Weddell seal (*Leptonychotes weddelli*). This seal species, which is adapted to fast-ice environments, occurs throughout the coastal region of Victoria Land but with larger abundances in areas where there are cracks through the sea-ice and there is underwater access (**Costa**). In connection with the Antarctic Pack Ice Seal (APIS) program in the 2000 austral summer, monitoring of seal populations revealed an apparent latitudinal gradient in crabeater seal (*Lobodon carcinophagus*) density along four north-south transect lines in the Ross Sea. Long-term population measurements of seal populations in McMurdo Sound further reveal potential connections with inter-annual and inter-decadal oscillations in the global atmosphere (Figs. 19 and 20).

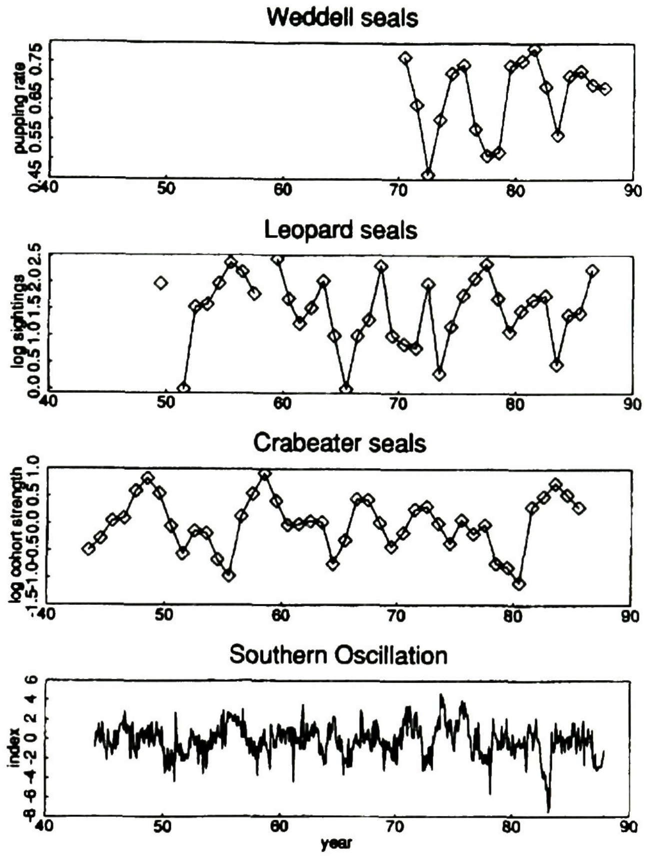


FIGURE 19: Time series of adult Weddell seals (*Leptonychotes weddelli*), crabeater (*Lobodon carcinophagus*) and leopard (*Hydrurga leptonyx*) seals in McMurdo Sound in relation to global atmospheric variability associated with the Southern Oscillation. From Testa et al. (1991).

FIGURE 20: Weddell seal (*Leptonychotes weddelli*) at Ross Island, Antarctica (P.A. Berkman).

- What are the sentinel species in the marine system for assessing environmental variability along Victoria Land?
- What environmental variations are reflected by changes in the distributions and abundances as well as physiological and biochemical processes of sentinel species or persistent biological assemblages?
- How does the structure and function of biological assemblages, such as deposit versus suspension feeding species, vary in relation to productivity?
- What are the recovery rates and responses of biological assemblages following habitat and pollution impacts from human activities?
- What are the biological baselines that should be developed along the latitudinal gradient of Victoria Land for assessing environmental variability across various time and space scales (Fig. 6)?

- How is the distribution of upper trophic levels and their prey influenced by oceanic fronts and ecological features associated with bathymetry and sea ice?
- Do biological features (e.g. prey composition and availability) have a stronger, direct influence on the distribution of upper trophic levels than do physical features (e.g. ice thickness, topography and ice-floe size)?

Marine-Terrestrial Transition Zone: As climate changes, coastal areas in the polar regions are periodically covered and uncovered by glaciological features. Following glacial retreat, uncovered coastal areas rebound from the diminished overburden of the ice, causing nearshore marine habitats to emerge above sea level (Fig. 14). Similarly, penguin and seal species move into terrestrial habitats from the ocean and add organic materials (**Costa**; **Emslie**) that which can eutrophy lakes and streams (Figs. 8c and 18). Moreover, glacial meltwater input into the marine environment can influence the dynamics of nearshore marine communities as well as the geochemistry of associated benthic species (**Lohmann et al.**). Consequently, the coastal transition zone in the polar regions contains ecosystem records that reflect both marine and terrestrial environmental variability.

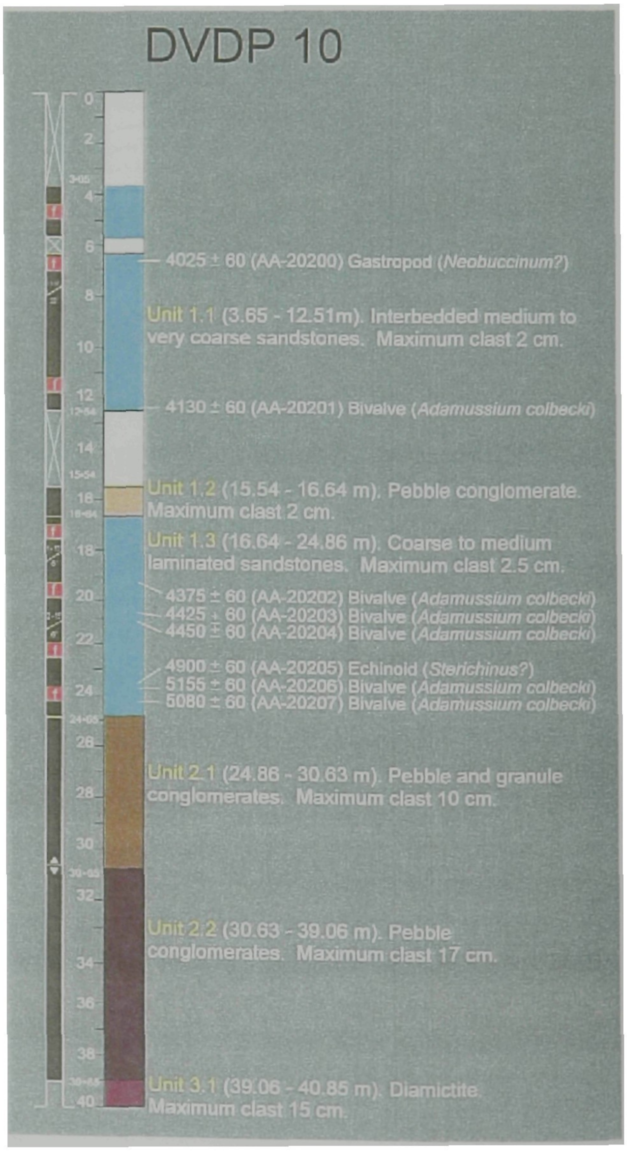


FIGURE 21: Sediment core from the Dry Valley Drilling Project (DVDP) Hole 10 in a prograding delta at the mouth of Taylor Valley, west McMurdo Sound, with radiocarbon-dated marine carbonate fossils. The sand deposits were introduced from meltwater streams in the terrestrial system and preserved since the mid-Holocene by sea-ice that insulated the beaches from high-energy wave erosion. Modified from Berkman et al. (1998).

Sea ice insulates the ocean from the atmosphere and minimizes water vapor transport into adjacent terrestrial systems. Consequently, sea-ice distributions will have an enormous influence on the:

- hydrology of terrestrial ecosystems;
- dynamics of terrestrial biota, which require liquid water for their production; and
- glacial accumulation, mass balance and dynamics;

Moreover, in regions along the Victoria Land Coast where the glaciers are connected to the East Antarctic Ice Sheet, water vapor transport from the ocean will influence:

- extension of outlet glaciers into the oceans as ice tongues; and
- glacial and ice-tongue conduits for katabatic winds which influence polynya formation.

An example of the environmental coupling between marine and terrestrial ecosystems in the coastal transition zone is reflected by the sediment core of the prograding beach in Explorers Cove, West McMurdo Sound (Fig. 21), with the integration of sea ice, stream flow, nearshore marine biota and terrestrial sediment deposition that are mediated by atmospheric dynamics.

Terrestrial Zone:

The terrestrial landscape along the Victoria Land Coast represents the largest ice-free region in Antarctica. Gradients in geomorphic features, climate and biological diversity exist across latitudes parallel to the coastline and perpendicular across elevations as well (**Lyons; Hawes et al.**).

Past climatic variations, including glacial advance and retreat as well as lake level rise and fall have dramatically impacted the terrestrial ecosystems. In Taylor and Wright Valleys, lake sizes have fluctuated greatly throughout the Pleistocene into the present. Large nutrient and organic reservoirs in the hypolimnia of the lakes have possibly been produced during the stage of the last major lake "drawdown" or climate deterioration (**Priscu**). Subsequent climatic amelioration has led to an increase in lake volumes and freshening of the surface waters. Past lake-level high stands have had important impacts on carbon deposition within the soils of the Taylor Valley, and affects on their biogeochemistry today. This overprinting of the modern ecological conditions by past climates is referred to as legacy, and it has greatly influenced the development and evolution of present-day terrestrial ecosystems along Victoria Land (**Wall; Moorhead**).

Figure 20: "Lift off" mat in permanently ice-covered Lake Hoare, McMurdo Dry Valleys, Antarctica at 8 meters depth. The cyanobacterial mats are buoyed by trapped gases (P.T. Doran).

By temperate zone standards, recent measurements demonstrate the importance of small changes in the environmental and climatic variables on the dynamics of the soil and aquatic ecosystems in Taylor Valley (**Doran**). It also is known from the McMurdo Dry Valley region that the lake ecosystems are unusual in that mixotrophy plays and extremely important role in their structure and function and that virus-like particles are in high abundance (**Priscu**). Recent work also strongly suggests that variations in stream flows to the lakes greatly affect phytoplankton composition. Linkages between glacial melt, stream flow and lake levels are clear and it is now certain that the biological systems are responding dramatically to subtle climate and physical environmental changes.

With desert levels of precipitation, Antarctica terrestrial species generally are restricted to ice-free coastal oases where there is a modicum of seasonal snowfall and melting. Algae have adaptations for dehydrating themselves as well as becoming insulated alive within sandstone rocks. There also are tiny mites, less than three millimeters in size with glycerol in their blood, nestling under rocks and in sand or other moistened habitats in temperatures below minus thirty degrees Celsius. Among these minute arthropods, which nonetheless are the largest animals on Antarctica, *Nanorchestes antarcticus* survives down to 85° South latitude as the most southern terrestrial animal on Earth.

Lakes and ponds exist all along the Victoria Land Coast from Cape Adare (~72°S) to the La Gorce Mountains and Scott Glacier region around 86°S. Although the soil biotic communities have very low diversity, suitable habitats for life are abundant throughout the region, especially at lower elevations close to the coast (**Doran**). Moreover, there are indications that there are similar ecosystem responses to environmental variability among widely separated areas. For example, South Lake Wilson at 80°S in the Darwin Valley has shown the same climatic responses as the Taylor Valley lakes over the past few decades, with a rise in lake level from 1975 to the early 1990's.

Modeling efforts can be used understand relationships between these environmental factors and the ecosystem dynamics, as in the Long Term Ecological Research (LTER) sites in Toolik Lake in the Arctic (**Hobbie**). Although the vegetation and faunal components vary greatly, analogous efforts in the McMurdo Dry Valleys LTER (MCM-LTER) provide insights about comparable environmental-ecosystem coupling in the southern high latitudes (**Moorhead**). Although the ecological dynamics of the McMurdo Dry Valleys is relatively well known compared to other sites in the region, ecological relationships along the Victoria Land gradient have not been established. Database tools, in particular Geographic Information Systems that allow ecological and environmental variables to be layered in a geospatial context, provide valuable opportunities for interpreting ecosystem dynamics (**Merry**). Understanding the dynamics of these high latitude ecosystems over time and space - in the polar extremes of the Earth system - is central to understand global responses to climate change.

With establishment of the MCM-LTER sites in 1993, long-term climate, stream flow, lake level and biological measurements have been conducted. Because long-term records will be collected in Taylor Valley and Write Valleys, other studies - no matter how limited in duration - can be compared with these datasets. In this way, the MCM-LTER can act as a major contributor to the overall Victoria Land gradient initiative - providing a unique opportunity as an experimental reference and ecological baseline.

Antarctic marine and terrestrial ecosystems are classic contrasts. Despite the freezing temperatures and extreme seasonality, Antarctic marine life thrives in one of the richest ecosystems in the ocean. Conversely, Antarctic terrestrial life is the most impoverished of any continent, with only a handful of species eking out a sparse existence under environmental extremes not unlike those on lunar or Martian landscapes. Together, these Antarctic biota reveal habitat limitations which generally control the production of biomass in the Earth system.

- What are the key environmental variables and terrestrial ecosystem components in lakes, streams and soils that should be measured and compared along Victoria Land?
- What is the "legacy" effect of nutrients and organic matter in terrestrial ecosystems along Victoria Land?
- What is the coupling between the hydrological cycle in terrestrial ecosystems and the dynamics of sea ice or other oceanographic phenomena along Victoria Land?
- Are changes in terrestrial ecosystem dynamics along Victoria Land synchronous at different latitudes?
- How the dynamics of terrestrial ecosystems across latitudinal gradients compare to elevation gradients along Victoria Land in relation to moisture availability?
- Do the magnitudes of terrestrial ecosystem variability change in a linear or step-wise fashion along Victoria Land?
- How does ecosystem variability along Victoria Land compare with analogous changes in the northern high latitudes or across other latitudinal gradients?

3. HUMAN DIMENSIONS

3.1 International Cooperation and Management

Antarctica exposes individuals to Earth system phenomena as well as a unique international system for maintaining an entire continent and its surrounding seas for *peaceful purposes only.* For all Antarctic issues, the decision-making forum involves the 1959 Antarctic Treaty that emerged from the International Geophysical Year in 1958-58. Since 1961, when the Antarctic Treaty was formally ratified, nations have been obligated to meet at *suitable intervals* for the purpose of (Antarctic Treaty, Article IX):

> *...exchanging information, consulting together on the matters of common interest pertaining to Antarctica, and formulating and considering and recommending to their Governments, measures in furtherance of the principles and objectives of the Treaty...*

This process of continuous consultation has fostered an international system of cooperation that has generated strategies for the *rational use* of resources as well as the overall protection of the Antarctic environment.

Beyond basic research on Victoria Land environmental and ecosystem variability, there is applied research and governmental policies that are related to human activities in the region. In 1991, the Antarctic Treaty consultative parties signed the Protocol on Environmental Protection to the Antarctic Treaty (PROTOCOL) to establish that all Antarctic habitats - both marine and terrestrial - were linked as *dependent and associated ecosystems.* Strategies for assessing the *minor or transitory* nature of environmental impacts were identified, particularly as they relate to the conservation of Antarctic fauna and flora. The PROTOCOL, which was ratified in 1998, also identified environmental principles that included the *wilderness and aesthetic values* of Antarctica as well as its intrinsic value as an area for conducting essential scientific research to understand the global environment (http://webhost.nvi.net/aspire).

Because of the increasing volume of humans around Antarctica, either as part of national programs or commercial expeditions, guidelines for environmental management were created. The PROTOCOL also instituted strategies for waste disposal and preventing marine pollution in the circumpolar Southern Ocean since most of the human transport is by ship, especially by the tourist vessels that now transport more than ten thousand persons each year as the largest human contingent in the Antarctic region. In essence, because there are multiple uses of Antarctica - from science to tourism to resource exploitation - it was necessary to design an holistic blueprint for Antarctic area protection and management. Beyond the gentleman's agreement among nations in the Antarctic Treaty, the PROTOCOL pertains to the shared responsibility of all entities in the Antarctic region - from national programs to commercial ventures to individuals.

The underpinning of resource management, whether in Antarctica or anywhere else in the Earth system, is the information available for understanding how humans impact natural systems. Across the spectrum, basic science focuses on natural processes in pristine ecosystems, often without considering the ramifications of the research in a societal context. Conversely, applied science is directed toward analyzing human impacts in disturbed ecosystems, often without establishing the appropriate natural baselines. In essence, interpreting the relationship between natural processes and human impacts requires information that integrates both basic and applied science. In this general context, the visionary international system in Antarctica is a model for designing resource policies that integrate information across the research continuum from basic to applied science (Fig. 21).

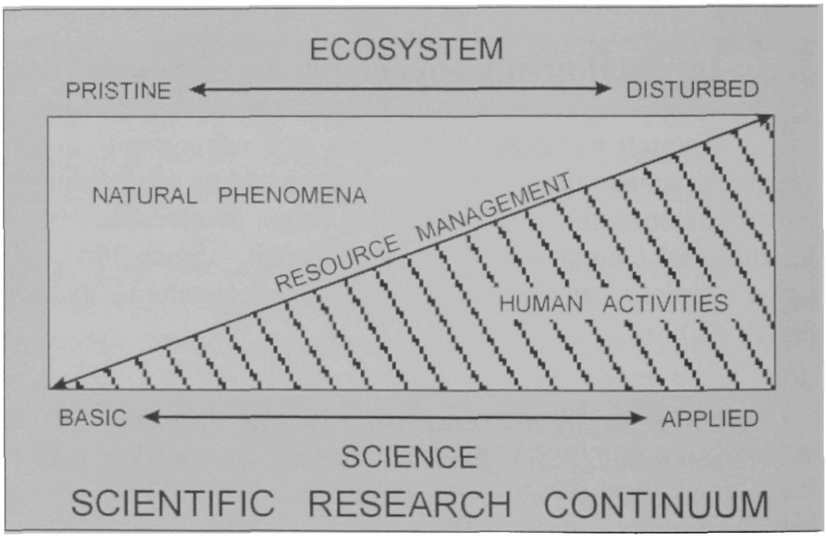


FIGURE 21: Scientific research continuum. Basic research focuses on the natural phenomena in pristine ecosystems whereas applied research focuses on disturbed ecosystems that are impacted by human activities. Integrated information from basic and applied research is necessary for environmental and resource management. From Berkman (1992, 2001).

Additional information on the specific policies of the Antarctic Treaty System regarding environmental protection, resource management and area protection for the Antarctic region, including Victoria Land, can be found on the enclosed CD-ROM of the *Antarctic Treaty Searchable Database: 1959-1999* which is being updated with new documents at http://webhost.nvi.net/aspire.

- What and where are the principal human activities and ecosystem impacts in marine and terrestrial environments along Victoria Land?
- Which of the Antarctic Treaty documents and policies are most relevant to human activities in marine and terrestrial ecosystems and environments across the latitudinal gradient of Victoria Land?
- What strategies should be developed for integrating basic and applied research, within and between nations, to mitigate human impacts along the latitudinal gradient of Victoria Land as well as at specific sites near stations and areas of tourist interest?

- How can the Victoria Land research initiative contribute to international environmental and resource management along the latitudinal gradient of Antarctica and throughout the Antarctic region?
- How can appropriate ecological baselines be developed for assessing human impacts before or after remediation efforts, as in the vicinity of Cape Hallett where oil contamination in melt pools may be affecting Adélie penguins from a nearby rookery (http://www.nsf.gov/od/lpa/new/press/01/pr0113.htm).

3.2 Public Outreach, Engagement And Education

Science provides a philosophical approach for life-long critical thinking, problem solving and creativity. Science also stimulates continuity in our world - across society over generations - by building on an ever-expanding base of knowledge that fosters technologies and opens opportunities for resource utilization. Moreover, in the Antarctic Treaty System, scientific cooperation provides common ground among nations independent of their political ideologies. In essence, science provides an educational framework for facilitating the sustainable development of communities across the Earth. In this Earth system context, Antarctica is an ideal template for teaching about the integration of science, economic and government policies across the planet.

There are a number of educational and outreach programs that have been implemented to provide insights about Antarctica for the general public. For example, each year the National Science Foundation (NSF), brings Kindergarten through 12th grade (K-12) teachers to Antarctica, as part of the *Teacher Experiencing Antarctica - TEA* program (http://tea.rice.edu/index.html), so that they can effectively share information from Antarctica with their students. Similarly, NSF has a Research Experience for Undergraduate (REU) program that enables college students to become directly involved with funded research projects. There also are research and education programs in universities that involve classroom activities in Antarctica, as with the NSF marine biology course or the *Gateway Antarctica* program through the University of Canterbury in New Zealand. In addition, there are classes that focus on the interdisciplinary aspects of Antarctica, like the *Antarctic Marine Ecology and Policy* capstone course which has been offered at universities in the United States since 1982 and involved over 900 students from more than 90 majors in 14 colleges at The Ohio State University since 1991 (Berkman 2002). Additional K-12 programs include *Blue Ice* (http://www.onlineclass.com/BI/blueice.html) and *GLACIER* (http://www.glacier.rice.edu/), which provide classroom activities and interactions with scientists in Antarctica over the internet for pre-college students at all levels. Moreover, there have been numerous multi-media activities with reports and live views of Antarctica as with the *Passport to Antarctica* program (http://passporttoknowledge.com/ptantarctica/ptantarctica2.htmlin). All of these educational and outreach programs have elements that would be meaningful to incorporate into the Victoria Land latitudinal ecosystem (LAT-ECO) research initiative.

- What types of education and outreach activities should be developed as part of the Victoria Land research initiative for K-12, colleges and universities, and the general public?
- How can interdisciplinary integration in the Victoria Land research initiative foster communication and collaboration among scientists studying the Earth system?
- What are the cross-cutting societal implications of Antarctica that should be brought to the attention of the general public?

4. SCIENTIFIC AND LOGISTIC IMPLEMENTATION

4.1 Research Coordination in the United States

The objectives of this workshop (Box 2) were to bring together a diverse group of scientists (Appendix 3) to share ideas on developing a biocomplexity research initiative to investigate environmental and ecosystem variability:

- along the latitudinal gradient of Victoria Land, Antarctica (Fig. 2); and,
- principally since the mid-Holocene (Figs. 7 and 8);

as a sensitive climate barometer where ice dynamics control marine, freshwater and terrestrial ecosystems (Figs. 3 and 5). Consequently, participants in this workshop identified:

- unique and exceptional features for studying this end-member in the global climate system (see Section 1.2);
- alternative hypotheses for assessing environmental and ecosystem trends along the latitudinal gradient of Victoria Land (Fig. 4);
- collaboration topics to facilitate discussions and interactions among scientists from diverse disciplines (see Section 1.3); and
- background research components and questions that should be integrated into the interdisciplinary research framework (see Sections 2.1 and 2.2).

To implement an efficient, cost-effective and well-coordinated research initiative that complements the goals and objectives of the United States Antarctic Program as well as the biocomplexity program at the National Science Foundation will require focused planning and ongoing active interactions among investigators.

4.2 International Research Coordination

Currently, logistic resources from the United States, New Zealand and Italian Antarctic programs are being used to conduct research activities along the entire Victoria Land gradient proposed for this initiative (Fig. 22). These programs provide helicopter and fixed-wing aircraft for deploying field teams that can be strategically staged from the different national research stations (Fig. 2) as well as remote sites with established fuel caches. These transport platforms will be the primary focus for the Victoria Land research initiative, with minimal requirements for the more competitively tasked ice-breakers or larger aircraft (i.e. C-130). It is anticipated that future research collaborations, information exchanges, database activities and logistic commitments among these programs will involve a Memorandum of Understanding, like the one that was crafted among the cooperating national programs for the Cape Roberts drilling project in McMurdo Sound.

At the workshop convened in conjunction with the Scientific Committee on Antarctic Research (SCAR) biology symposium in Amsterdam in August 2001 (Box 1), additional information about international interests and activities associated with the Victoria Land latitudinal gradient initiative was provided. This workshop involved scientists and national representatives from Estonia, Germany, Italy, Japan, New Zealand, United Kingdom and the United States Representatives from the Italian and New Zealand Antarctic programs indicated that they intend to have their ships (i.e. *Italica* and *Tangaroa*, respectively) operating in the Ross Sea during 2003-04 in conjunction with their national implementation plans for the Victoria Land latitudinal gradient initiative. These ship-borne activities and existing environmental monitoring facilities provide opportunities for developing an initial Memorandum of Understanding among the three principal national Antarctic programs in the Ross Sea region (Fig. 22). Additional information about the workshop report can be found on the Byrd Polar Research Center website (http://www-bprc.mps.ohio-state.edu/victorialand)

Figure 22: National Antarctic research programs in the Ross Sea region. **(upper panel)** *McMurdo Station* (77°51' South, 166°40' East) operated year-round by the National Science Foundation as part of the United States Antarctic Program. McMurdo Station was established in 1955 for the International Geophysical Year (IGY) which ran from June 1, 1957 through December 31, 1958. **(middle panel)** *Scott Base* (77°51' South, 166°46' East) has been operated year-round since the IGY as part of the New Zealand Antarctic Research Program. **(lower panel)** *Stazione Baia Terranova* (74°41' South, 64°6' East) has been operated by the Italian Programma Nazionale di Ricerche in Antartide during the summer since 1985. See Figure 2 for station locations.

4.3 Next Steps

Overall, implementation and application of the Victoria Land biocomplexity research initiative is multi-faceted. In addition to involving diverse national programs and logistics, this research initiative will contribute in meaningful and novel ways to:

- Interdisciplinary interpretations will be developed for interpreting climate impacts on the physical and biological coupling and dynamics of adjacent marine and terrestrial ecosystems and environments;
- Human dimensions of environmental change will be assessed in relation to local and global impacts with regard to existing or emerging management for protected areas or resource activities; and
- Existing disciplinary research activities will benefit from enhancing the spatial scope and opportunities for experimental interpretation; and

- Logistics and cost-effectiveness coordination among collaborating national programs.

Recommendation 1:

A focused planning meeting should be convened among an appropriate group of United States scientists who will identify:

- overall science goals, objectives and integration strategies;
- timeframes;
- funding opportunities and involvement of new investigators;
- logistic requirements and strategies;
- proposal requirements and review strategies; and,
- national and international administrative frameworks and requirements.

It would be optimal to convene this United States science and logistic planning meeting by Spring 2002 to maintain the momentum of ongoing discussions (Box 1) and to facilitate strategic coordination (including workshops) with the New Zealand, Italian and other national Antarctic programs who would contribute significantly to future implementation.

Recommendation 2:

A coordinated interdisciplinary proposal for geographic information system (GIS) analyses should be submitted to the National Science Foundation, either as a stand-alone proposal to the Office of Polar Programs (June 2002) or as part of a comprehensive biocomplexity proposal to the Division of Environmental Research and Education (March 2002). This GIS activity will be an important step toward implementing the Victoria Land program in a manner that:

- fosters comprehensive assimilation of background data;
- facilitates hypothesis development and refinement; and
- provides a robust tested framework for ingesting future datasets when the initiative is ongoing and fully implemented.

This initial GIS proposal also would be a cost-effective complement (without initial logistic requirements) from the United States for developing balanced initial commitments among the three principal Antarctic programs involved with the Victoria Land initiative (Fig. 22).

Recommendation 3:

The Victoria Land latitudinal gradient initiative should be implemented in phases that consider the:

- operational and funding frameworks;
- interaction among existing projects and involvement of new investigators;
- proposal review processes; and,
- overall practicality and cost-effectiveness of coordinating this project,

in an interdisciplinary context among the Italian, New Zealand, United States and other contributing national Antarctic programs.

Phase 1: Informal networking and logistic coordination among funded scientists from the different national Antarctic programs who already share common research interests (e.g. nearshore marine benthic ecology; limnology and terrestrial ecology; meteorology; ice-core paleoclimatology; penguin ecology and paleoecology; and glacial geomorphology).

Phase 2: *Initial Memorandum of Understanding* among participating national Antarctic programs that defines, in principle, the:

- goals and objectives;
- anticipated products and coordination;
- timeline and scope;
- proposal and program review procedures

for this international research initiative. At this initial international agreement stage, substantive contributions from the national Antarctic programs would involve existing that are known or anticipated, such as:

- environmental monitoring networks (e.g. automatic weather stations and global positioning systems);
- data-storage facilities (e.g. National Snow and Ice Data Center in the United States);
- major logistic commitments (e.g. *Italica* and *Tangaroa* from the Italian and New Zealand Antarctic programs, respectively);
- mapping and photographic templates (e.g. Landsat 7 photo-mosaic imagery from the United States); and
- International TransAntarctic Scientific Expedition (ITASE) ice-core records over the past two centuries collected along the polar plateau parallel to the Victoria Land Coast.

as well as data assimilation strategies that do not involve logistic requirements (e.g. geographic information system approaches).

Phase 3: *Principal Memorandum of Understanding* that would elaborate on the *Initial Memorandum of Understanding* and identify additional commitments among national programs for:

- strategic locations for camps and caches;
- field season duration(s) at the strategic locations;
- scientific and field equipment and facilities;
- scientific and safety personnel;
- configuration of principal transport logistics (i.e. fixed-wing aircraft and helicopters);
- collaborative mechanisms within and between scientific disciplines and national programs;
- appropriate administrative infrastructure and coordination; and
- program assessment procedures and stages.

APPENDIX 1

THE POSSIBLE CONTRIBUTION OF THE CLIMA PROJECT TO THE VICTORIA LAND PROJECT

Andrea Bergamasco, Serena Fonda Umani and Giancarlo Spezie

In the framework of the CLIMA project, (1997 – 2001) studies have been carried out at different scales from basin wide to mesoscale, in order to identify basic mechanisms and relevant areas. In particular, within the project, the circulation in the Ross Sea (RS) has been investigated by hydrological and current measurements and by diagnostic models. The flow field within the RS has proved affected by bottom topography, by the presence of the Ross Ice Shelf (RIS), by the mass exchange at the continental slope and by localized water mass formation phenomena, which represent an important component of the Antarctic Bottom Waters (AABW). The smaller scale processes which determine the physical and biogeochemical dynamics of the RS as well as of global mechanisms are still to be clarified and assessed.

In the formation processes, a major mechanism takes place, that of water mass ventilation. Gas transfer coefficients can be estimated on the basis of radon deficit in the upper layers of the ocean, and that estimate can be extended to the greenhouse gases which are exchanged at the sea/atmosphere interface. Moreover, many of the projects set in the Southern Ocean have been designed to assess the flux of CO_2 between water and atmosphere. The process is affected by two factors: the "biological pump" and the dense water formation. The different efficiency of the biological pump can lead to CO_2 release into the atmosphere through respiration or formation of organic matter, which, trapped in the bottom waters, can be confined in the deep ocean circulation for decades or centuries.

Particularly during the last two cruises two area were investigated in this respect: the coastal polynya and the continental slope Polynyas are areas where interactions among air, sea and ice are the strongest, and they have relevant effects on the formation and spreading of sea ice, on dense water production and on water ventilation, on biogeochemical fluxes in terms of gas fluxes and on vertical convection as a mechanism for carbon transport. Earlier activities within the CLIMA project in the Terranova Bay (TB) area has produced an analysis of the hydrological and biogeochemical characteristics of the water column on the basis of a three year time series of data collected by moored instrumentation and on the suveys carried on during the two cruises

On the continental slope the researches was aimed at improving the understanding and modelling of the outflow processes taking place on the antarctic continental slope, utilizing both multidisciplinary measurements and phenomenological and numerical models. Earlier studies have allowed to follow the spreading of those waters up to the slope, where they undergo substantial modifications due to meso- to small scale processes in the interaction with the front generated by the presence of the Circumpolar Deep Water (CDW). During the last cruise (2001) we conducted a mesoscale investigation focussed on the repeated observation of two areas, identified during the 1997-98 cruise, where two analogous phenomena involving two different shelf water masses (HSSW and ISW) take place. The formation of these waters is characterized by profoundly different interaction mechanisms at the sea-atmosphere interface. A critical parameter is constituted by the respective age of the water masses, whose assessment represents therefore on of the main goals of our research.

During the two cruises (1997-98 and 2001) extended surveys on microbial planktonic communities were carried out to investigate the carbon partitioning among the different size classes, and particularly during the 2001 cruise, several dilution experiments were performed from Cape Hallet to near McMurdo Sound in order to experimental determine the carbon fluxes through the first steps of the food web.

CLIMA project can usefully interact with the proposed Victoria Land project by studying the open ocean processes, both from a hydrodinamical point of view as well as from a biological processes oriented study that can lead to a better understanding of the exchanges of the coastal area with the open sea and viceversa.

METEOROLOGICAL PROCESSES AFFECTING VICTORIA LAND AND THE DATA AVAILABLE TO STUDY THEM

David H. Bromwich and Andrew J. Monaghan

Introduction

The terrestrial and marine ecosystems of the Victoria Land, Antarctica region are closely tied to meteorological events. Katabatic and barrier wind events play a significant role in the presence of sea ice cover and open water, as well as ocean-atmosphere heat fluxes (e.g. Kurtz and Bromwich, 1985). Mesoscale cyclogenesis in the Terra Nova Bay (TNB) and Byrd Glacier vicinity occurs frequently – an average of 2-3 and 1-2 mesoscale cyclones (less than 1000 km diameter) each week, respectively (Carrasco and Bromwich, 1996). Rugged terrain (mountains > 3,000 m), a sharp contrast in temperature, wind intensity, pressure and moisture in the continental-marine transition zone, and remoteness make understanding and predicting weather and climate in Victoria Land difficult. Generally, all available data - Automatic weather stations (AWS), Automatic Geophysical Observatories (AGO's), rawinsondes, satellite imagery, global reanalysis and forecast models, and observations from McMurdo Station and ships plying the Ross Sea – are needed to understand the weather on various scales. Still, these data are often not enough, as observations frequently lack the necessary spatial resolution, or are unavailable for a desired time period. This abstract is meant to give 1) a brief synopsis of the atmospheric processes in the continental and marine regions of Victoria Land, and 2) an outline the various sources of meteorological data available.

Atmospheric Processes: Continental

The terrestrial regions of Victoria Land extend upward from sea level in the mountainous coastal transition zone to a high plateau ranging from 2,000 – 3,000 m in elevation. Dense, cold air from the interior of Antarctica, vast open areas with few obstacles, and a continuous downward slope toward the coast set up ideal conditions for katabatic winds. These winds occur year round, but are most frequent in winter due to the continuous supply of cold air diverging from central Antarctica. When katabatic winds reach the Victoria Land coast, they funnel through relatively small areas defined by the major glacial valleys in the Transantarctic Mountains. The two most notable areas in Victoria Land are the Byrd/Mulock/Skelton glaciers to the south of Minna Bluff, and the valleys (Reeves/David/Priestley glaciers) which drain into TNB (Bromwich, 1992).

Due to the high elevation, few synoptic-scale cyclones penetrate the inland continental regions of Victoria Land. Year-round low temperatures and nearly 100 % glacial ice coverage limit moisture from the few cyclones that do pass over. Consequently, low cloud amounts and very little precipitation (appx. 5-15 cm/yr) are characteristic (Giovinetto and Bentley, 1985). The coastal mountains receive somewhat more precipitation (appx. 15-30 cm/yr, with more in localized areas).

Atmospheric Processes: Marine

The marine regions of Victoria Land vary significantly between winter and summer. In winter, this ecosystem is more characteristic of a continental regime, due to extensive sea-ice cover, which curbs the ocean-atmosphere heat fluxes. However, persistent offshore katabatic winds contribute to the formation of regions of open water (polynyas). The intense heat flux present in polynyas is thought to be responsible for large-scale ice production, as well as contributing to the formation of dense, Antarctic Bottom Water, which affects oceanic thermohaline circulation on a global scale (e.g. Gordon and Comiso, 1988). Two widely recognized coastal polynyas in the Victoria Land region are the TNB polynya (e.g. Van Woert, 1999), which forms to the immediate north of the Drygalski Ice Tongue, and the Ross Sea Polynya (e.g. Bromwich et al., 1998), which forms the east of Ross Island, bounded on the south by the Ross Ice Shelf.

Similar to katabatic winds, barrier winds are another important process in Victoria Land's marine system. When cyclones are present over the western Ross Ice Shelf / Ross Sea, easterly airflow is toward the Transantarctic Mountains. The mountains block the eastward flow and, in conjunction with the Coriolis effect, divert it to the north. These winds are in geostrophic balance with the pressure gradient normal to the mountains, caused by the damming of stable air and subsequent increase in boundary layer depth (O'Connor, et al., 1994). Barrier winds are significant contributors to polynya formation and ocean-atmosphere heat fluxes.

As discussed above, mesoscale cyclogenesis occurs frequently year–round. However, due to the presence of sea-ice cover, wintertime cyclones near TNB are more difficult to detect owing to the general lack of a cloud signature in satellite imagery, and the absence of precipitation. Generally, wintertime cyclones can be identified by assessing pressure and wind fields from available AWS observations. In summer, the presence of open water and associated cloud development make these events much more easily recognizable in satellite imagery.

There are many ingredients required for mesoscale cyclogenesis to occur, which limits the regions in which they often form. The zones near TNB and Byrd glaciers are such regions, providing a confluence of strong katabatic winds (Bromwich, 1991), steep baroclinic zones (summer), and moist air advection from synoptic-scale cyclones to the north of the Ross Sea.

Synoptic-scale cyclones generally pass to the north of the Ross Sea, contributing to and supplementing mesoscale cyclones. However, they do occasionally move into the western Ross Sea, affecting regional weather.

Data Availability

Relative to more populous areas of the globe, a remarkable amount of atmospheric data is collected in Victoria Land. The United States, Italy, and New Zealand all have bases in the region, allowing for an extensive AWS network, AGO's, twice-daily rawinsondes, land / ship observations, and high-resolution satellite reception from the frequent passes of polar-orbiting satellites (Figure 1). In addition, global analyses from the NCEP/NCAR Reanalysis, as well as the ECMWF Operational and ECMWF Reanalysis models are useful for observing meteorological fields on a large-scale. Recently, a numerical weather prediction program, AMPS (Antarctic Mesoscale Prediction System), has been implemented in the 2000-2001 field season. AMPS employs the Polar MM5, a hybrid version of the Pennsylvania State / NCAR Fifth Generation Mesoscale Model, modified to represent parameterizations over extensive ice sheets (Cassano et al., 2001). The Polar MM5 has been well received by forecasters at McMurdo, and its usefulness as a tool for predicting, explaining, and reconstructing weather events is now being realized. Links for the various meteorological data available for Victoria Land are provided in Table 1.

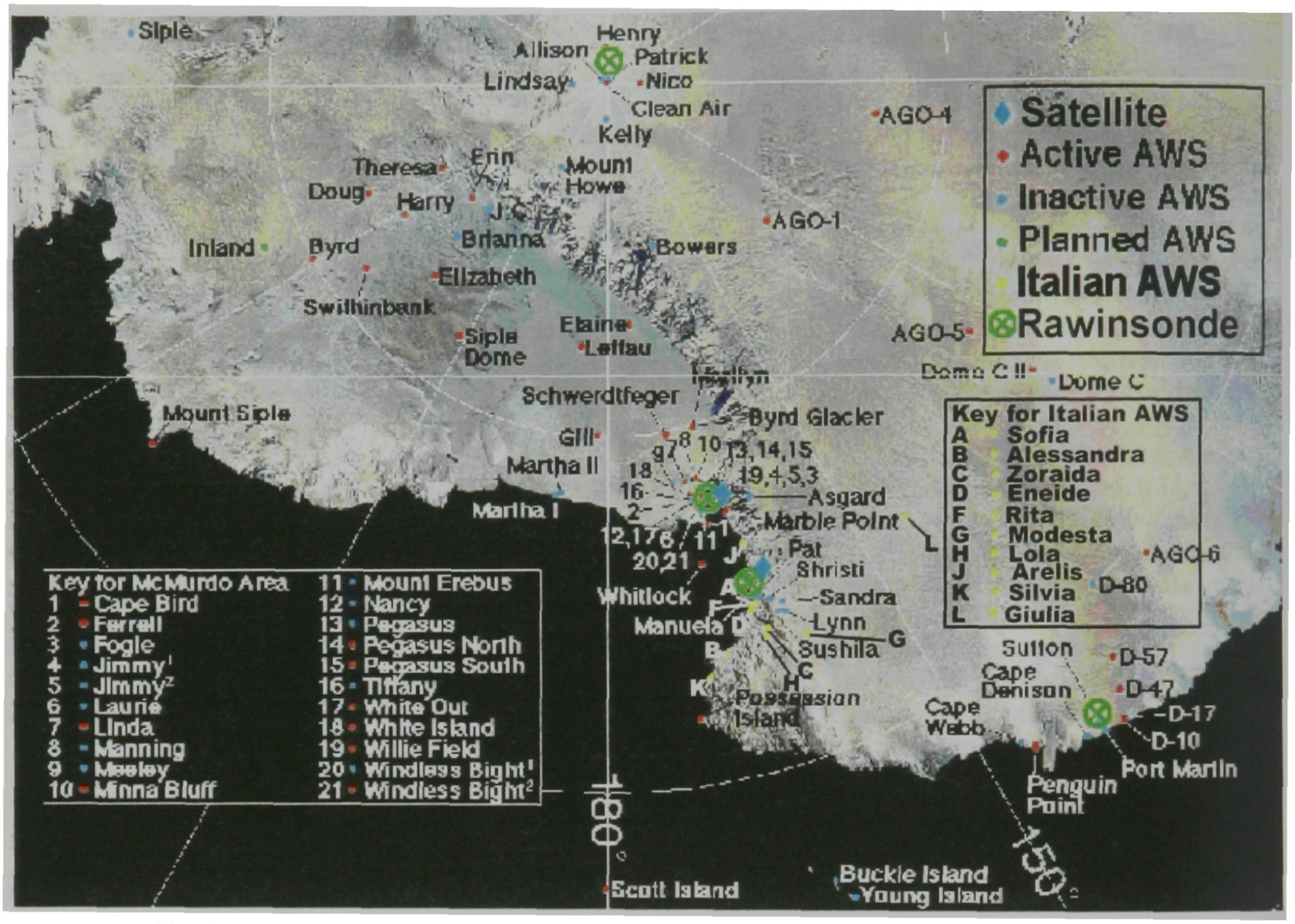


Fig. 1 . Locations of Automatic Weather Station (AWS), Rawinsonde, Automatic Geophysical Observatory (AGO), and satellite pass receiver sites. (Adapted from University of Wisconsin, Space Science and Engineering Center.)

Table 1. Sources of atmospheric data for Antarctica

Who	Data Type	Internet Address	Contact	Email
University of Wisconsin, Antarctic Meteorological Research Center (AMRC)	Composite satellite data, polar orbiter satellite data, model analyses and forecasts (NCEP MRF and Wind and Wave Forecast Model, ECMWF), Synoptic observations, Rawinsondes, water vapor winds, cloud drift winds, USAP Research Vessel observations, AWS (USAP) observations, AGO observations, UK/BAS observations, Manned Station Monthly means, Palmer Station monthly summaries	http://uwamrc.ssec.wisc.edu/aws/	Charles Stearns	chucks@ssec.wisc.edu
University of California at San Diego, Arctic and Antarctic Research Center	NOAA and DMSP, HRPT and OLS satellite product archives - available by request Data collected is from McMurdo and Palmer Stations, as well as the ships USCGC POLAR SEA, USCGC POLAR STAR, and USCGC HEALY	http://arcane.ucsd.edu/	Dan Lubin	dan@arcane.ucsd.edu
National Centers for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR)	Global Numerical Analysis Model data. NCEP/NCAR Reanalysis Archives.	http://wesley.wwb.noaa.gov/reanalysis.html	Wesley Ebisuzaki	ebis@wesley.wwb.noaa.gov
University Corporation for Atmospheric Research (UCAR)	ECMWF Operational Analysis, Reanalysis, other modeling data	http://dss.ucar.edu/catalogs/all_titles.html	Joey Comeaux	joey@ucar.edu
National Climatic Data Center	Archived Weather Data. Usually a cost $$.	http://www.ncdc.noaa.gov/	n/a	n/a
Voluntary Observing Ship Program (VOS)	Archived data from several thousand ships - may cost $$	http://www.pmo.noaa.gov/	n/a	n/a
Antarctic Mesoscale Forecast System Page	Near Real Time NWP model (MM5) for McMurdo and Antarctica	http://www.mmm.ucar.edu/rt/mm5/amps	James Bresch	bresch@ucar.edu
Byrd Polar Research Center (BPRC)	Near Real Time NWP model (MM5) for McMurdo and Antarctica	http://www-bprc.mps.ohio-state.edu/ANWP	David Bromwich	bromwich@polarmet1.mps.ohio-state.edu
Raytheon Polar Services	Complete Meteorological Data archives from McMurdo, Palmer, and South Pole Stations, purchased from NCDC and possibly available for free distribution to research associated with USAP.	http://rpsc.raytheon.com/	Manan Moyher	MOYHERMA@polar.org
Italian Antarctic Program	Data from Italian AWS, rawinsondes, and high-resolution satellite imagery. Available on request	http://www.wmo.ch/web/www/OSY/Ant-cat-Italy.html	Andrea Pellegrini	pellegrini_a@casaccia.enea.it
New Zealand Antaractic Program	n/a	http.//www.antarcticanz.govt nz/	n/a	info@antarcticanz.govt.nz

ITALIAN REPORT ON THE VICTORIA LAND LATITUDINAL GRADIENT PROJECT

Riccardo Cattaneo-Vietti

The Victoria Land Coast (Ross Sea), including the Ice Shelf section south of McMurdo Sound, extends across nearly 18 degrees of latitude, from Cape Adare at 68 S to the La Gorce Mountains at 86 S and represents the most extensive latitudinal gradient along the Antarctic coastline that can be studied within the existing logistics of national programs. Recently, we have recognised the opportunity to develop a large-scale, multidisciplinary project to study the unique inland and marine communities along the Victoria Land Coast.

The Ross Sea region contains a number of environmental (ecological) spectra relating to cold, aridity, solar radiation, UV, light/dark conditions and highly variable sea ice dynamics including a major polynya. The land and coast within the Ross Dependency across this wide latitudinal range includes a variety of marine, terrestrial and freshwater habitats. Some of these systems are unique to the Antarctic.

Moving along the Victoria Land Coast, changes of environmental parameters affect all the inland and marine environments, starting from nutrient cycles and primary production to top predators, leading to strong changes in community structure and function at any trophic level. Overlapping the gradually changing variables, abrupt local transitions and peculiarities may occur, because of strong wind action, peculiar edaphic features, melt-water inputs, grain size and sea-bottom morphology. It is presumable the presence of critical depth/altitude, over which community structures and life cycles are affected, while, beyond these limits, communities features should maintain relatively homogeneous along the coast.

A comprehensive study of the Victoria Land Coast will yield invaluable information on the dynamic interactions between terrestrial and shallow water ecosystems, especially in light of current efforts to understand the impacts of climatic shifts in Antarctica.

This project would be conducted within a framework of international collaborations between PNRA (Italian Antarctic Research Programme) and other Antarctic research Institutions, at different locations (*e.g.* Cape Adare, Cape Hallett, Coulman Island, Kay Island, Cape Washington, Edmonson Point, Terra Nova Bay, Cape Russell, Cape Roberts, Marble Point, Dry Valleys, McMurdo Sound, Brown Hills, Beardmore Glacier and La Gorce Mountains).

Research Priorities:

- **To evaluate the environmental gradients linked to latitude**
- **To relate community transitions along the Victoria Land Coast to geomorphological and hydrological features**
- **To evaluate biochemical, physiological and other adaptive responses of representative organisms across longitudinal and altitudinal/bathymetrical transects**
- **To estimate anthropogenic impact and the importance of the latitudinal gradient in the xenobiotic accumulation pattern in organisms**
- **To measure biodiversity at species and genetic level**
- **To test the progressive emergence of benthic assemblages**

Background

Environmental Gradients Linked to Latitude

Significant differences in the marine and non-marine physical environment are found in temperature, wind stress, solar radiation, UV-B, humidity, melting and pack-ice coverage. They affect living organisms both in terms of their minimum and maximum values but also in their seasonal variability. Synoptic measurements of main parameters should be carried out and past data-sets should be analysed and modelled.

Environmental changes over such a wide latitudinal range at one point in time can be used to mimic environmental changes at one point in space over a long time span. A latitudinal gradient can therefore be used to study the effects of potential changes in regional climate that may or may not be associated with global change, as well as providing a range of environmental conditions for more fundamental studies. Underlying this is the phenomenon of "Polar focussing" whereby a given change in latitude in the Polar Regions is followed by a greater change in environmental variables than a similar latitudinal change in the temperate or tropical regions. Polar focussing provides an additional advantage to the use of a gradient approach to study environmental change in the Ross Sea region.

Three major systematic environmental gradients that are significant to understanding Victoria Land environments are latitude, altitude/depth and distance from the coastline. These three gradients have different spatial scales, environmental variables and environmental constants. None of these gradients alone are simple surrogates for environmental change. However, combining these will result in a better understanding of our current ecosystems and an increased predictive knowledge of the effects of future environmental change.

Community Transitions and Spatial Variability Related to Geomorphological and Hydrological Features

Geographic and hydrological out-standings may constitute barriers affecting the distribution of inland and marine communities, causing patchiness and population isolation.

As much as it concerns water column communities, studies have been carried out regarding organic matter flux and fate, plankton biomass, krill and fish larvae distribution along the Victoria Land coast, in terms of species distribution, abundance and genetics.

As much as it concerns benthic studies, after the pioneer works carried out by USA and New Zealand in the 50-70s, the attention of the researchers has been focused only on the structure and dynamics of shallow waters communities close to the bases. The comparison between the structure and composition of the communities, the life histories and the role of the main key species stresses relevant differences between McMurdo and Terra Nova Bay, whose patterns could be related to a gradual change along the latitudinal gradient or be the consequence of abrupt changes related to geomorphological and hydrological barriers. Strong gradients have been already documented along the Ross Sea as regards to fluxes at the water-sediment interface and biogenic sedimentation rates. These characteristics, coupled with complex geomorphological features, determine large spatial variability in benthic community composition, density and stratification pattern along the Victoria Land transect.

The Terra Nova Bay polynya, the Drygalski Glacier and the Ross Ice Shelf represent in fact significant physical features which could affect communities along the Victoria Land Coast, affecting community structure, genetic differentiation and adaptations.

These barriers could strongly influence the trophic dynamic of marine ecosystems, as strictly related to physical, chemical and biological processes occurring either in the water column and bottom sediments. Pelagic and benthic compartments are coupled in marine system and interact through the material and energy flows also determining the evolution of planktonic and benthic communities.

Recently, particular attention has been focused on the structure and dynamics of the sea-ice community which has a fundamental role in primary production processes.

The production of faecal material by the zooplankton communities is of interest in the evaluation of OM pool and total OM flux. A great role is played in this framework by the microbial community whose different metabolic pathways mainly concurred to the regeneration processes (mineralization) and the degradation of organic compounds.

Most of scientific activities on fish communities have been conducted at Terra Nova Bay and Dumont D'Urville. In addition, collaboration has been established with Australian researchers working at Casey Station. Particular attention has been given to reproduction, larval stages, recruitment (previous data stress strong latitudinal variations in reproductive strategy of some species) and predator-prey relationships.

Till now, population genetic studies have been carried out on plankton and nekton species, in terms of analysis of inter- and intra-specific genetic diversity. Investigations have been performed by means of molecular markers such as sequence polymorphism at mitochondrial DNA, amplified fragments length polymorphism (AFLPs) and microsatellite nuclear loci. The results obtained so far indicate the existence of distinct genetic pools in the different areas of the Southern Ocean for both fish and krill species. Such genetic heterogeneity is more pronounced in the two fish species studied (*Pleuragramma antarcticum* and *Chionodraco* spp.) as compared to the Antarctic krill *Euphausia superba.*

Biochemical, Physiological and Other Adaptive Responses

The biology of Antarctic organisms is strongly affected by temperature, light, food and water availability most of which change with latitude. Anyway, seasonal and interannual variations may complicate the comprehension of the latitudinal gradient effect on community structure, but this variability itself may be a feature of latitude.

Moreover some terrestrial features vary in a non-linear manner to latitude, such as the extent of freeze/thaw cycles which impart considerable stresses on organisms, the oceanic influence, affected by pack-ice persistence and wind action, and, finally, the altitude which has a marked bearing on temperature, ands can mimic the solar radiation effects along the latitudinal gradient.

Baseline information on the ecology and biology of terrestrial and marine organisms is important for interpreting possible community responses to fluctuating environmental parameters and in the perspective of evaluating possible effects of global change. Moreover differences in distribution, abundance and growth rate of $CaCO_3$ utilising organisms (algae, molluscs and echinoderms) may be hypothesised, due to the influence of latitudinal changing or edaphic parameters on biocalcification.

Water is the principal limiting factor in terrestrial ecosystems and eventual climatic shifts (temperature and precipitation) could strongly affect water availability and element (essential and toxic) leaching.

Inland, most research was performed within the SCAR- RiSCC (Regional Sensitivity to Climate Change) in Antarctic Terrestrial and Limnetic Ecosystems, focusing on survival strategies, genotypic and phenotypic plasticity, inter-specific competition and community dynamics, biogeochemical cycles (carbon and nutrients, growth and primary production, organic matter decomposition, bioavailability of essential and toxic elements).

Continental Antarctica presents only few non-marine environments suitable for life. Microbial flora and fauna (cyanobacteria, tardigrades, nematodes, rotifers) have several strategies (e.g. anhydrobiosis) that allow them to be dispersed by wind and to establish in some of the most extreme environments on earth. However, local soil conditions or water conditions (salinity, anoxia) can result in local patchiness in community structure and composition.

In these environments, biological communities microalgae are ever present. In some cases, they represent the main component both quantitatively and qualitatively (for example benthic and floating algal mats). During the last decade (1989-1999) samples were collected from different Antarctic non-marine habitats: lakes and ponds, meltwaters, mosses, ornitogenic soil, ahumic soil, snow and rock, covering most of deglaciated zones of northern Victoria Land (from 72°36' S to 75° 46' S).

Studies have been performed about elementary composition, relation with substrate and distribution of lichenes according to latitude, altitude, distance from the coast, birds presence and other environmental features.

Regarding the extremophilic microorganism (thermophiles, alophiles and psychrophiles), several species of thermophiles (one of which, *Bacillus thermoantarcticus*, is a novel species) and alophiles have been isolated from Mount Melbourne and Edmonson Point. Taxonomical work has been carried out, as well as characterisation of enzyme content and membrane lipids. A psychrophile (*Psychrobacter* sp. TAD1) has been isolated from fresh continental water. Two glutamate dehydrogenases, each specific for either NAD or NADP, have been purified and characterised, with respect to cold-adapted features.

A great bulk of data has been collected about sea-ice microalgal communities and their adaptations in relation to temperature, salinity and light. These organisms produce secondary metabolites, among which carotenoids, of relevant interest, as they represent "fine chemicals" of commercial interest.

At sea, researches were carried out focusing mainly on fish respiration rate and metabolism. Primarily attention was given to differences in structural and functional characteristics of haemoglobin in half of the total species number of the sub-order Notothenioidea and in other sub-orders (Zoarcoidea), giving particular attention to thermodynamic oxygen binding properties and to tri-dimensional crystallographic structure in species having functionally different haemoglobins.

Secondarily, studies were performed on metabolism (enzymatic systems playing a key role in the metabolic pattern), in particular on blood red cell glucose-6-phosphate dehydrogenase, liver L-glutamate dehydrogenase, muscle phosphorilase, blood and gills carbonic anhydrase, in terms of structure and catalytic behaviour at changing temperatures. Some of these enzymes are studied relative to different physiology of species with and without haemoglobin.

Studies regarding reproductive adaptations have been performed on some of the most conspicuous benthic species, stressing relevant changes in tempos and timing of spawning, that can be related to latitude, although interannual and local changes occur, which may mask latitudinal effects.

Ecotoxicology

The long distance transport of air borne chemicals (such as some persistent organic pollutants), the impact of increasing levels of UV radiation (due to the stratospheric ozone depletion) and focal sources of physical-chemical disturbance associated with scientific bases and tourism depict the opportunity of developing integrated ecotoxicological studies.

The Southern Ocean isolates Antarctica from other oceans and lands therefore volatile contaminants can reach it mainly via the transport of air mass. Furthermore, the southern hemisphere is mainly occupied by oceans and land is relatively less populated than the northern hemisphere so that the contamination pattern from the Northern high latitudes to the Southern high ones follows a latitudinal gradient.

Remote areas including the Polar regions were considered to be pristine until contamination was first documented in the 1970's.

Global contamination by persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs) and organochlorine pesticides has been well documented. Oceans are a major sink for persistent chemicals, which are transported from continental areas by atmosphere and oceanic currents. Global distillation or fractionation by condensation in cold polar environments has been proposed as a mechanism whereby the polar regions may become sinks for some POPs. They vaporize from source areas in the mid-latitudes and are transported to the high latitudes by air mass movements. In relation to the volatility of the various POPs, they condense at different ambient temperatures and fall out on the earth surface again. Condensation and falling out depend on physicochemical properties of molecules and air temperature so chemical deposition is strictly correlated to them and the process has been defined as "global distillation".

This is why it is expected that the presence of POPs may follow a latitudinal gradient. Due to the low temperatures, POPs degradation is very slow in the polar regions. Ice is a cold trap for POPs and it can release them thus these compounds may enter in the trophic webs where they bioaccumulate and biomagnify. Migratory animals, especially top predators (such as South Polar skua and other birds, whales), may be another source of pollutants with their excrements and carcasses.

Among POPs, polychlorinated biphenyl (PCBs), polychlorinated-dibenzo-*p*-dioxins (PCDDs), polychlorinated-dibenzofurans (PCDFs), polychlorinated-naphthalenes (PCNs) and chlorinated pesticides (i.e. *p,p'*-DDE) have already been detected in Antarctic organisms. All these compounds are industrial chemicals that exhibit several common properties such as high lipophilicity (increasing with chlorination), high stability to breakdown by acids, bases, heat, hydrolysis.

The use of key species as sentinels (bioindicators) for monitoring environmental changes around Antarctica has been stressed by SCAR programs, such as EASIZ. However, very limited investigations have dealt with the development and validation of biomarkers in Antarctic organisms, based on responses at different level of biological organization, for early detection and prediction of environmental changes. Thus the improvement of our knowledge about the biochemical, molecular, genetic and physiological responses to a changing environment along a north - south continuum appears to be a significant issue to be addressed.

Among the numerous biological responses described as biomarkers in the last two decades, those based on the cellular antioxidants and on the susceptibility to oxidative stress are of increasing interest for ecotoxicologists, since several physical and chemical perturbations are known to exert their toxic effects through the enhancement of intracellular generation of reactive oxygen species. Antioxidant defenses of Antarctic key species were shown as useful biomarkers for detecting pollutant effects under both field and laboratory conditions; moreover, variations of the redox status appeared closely related to other important damages including lysosomal membrane destabilization. The antioxidant system is also strictly involved with the impact of UV radiation on biota. In fact, despite many invertebrates are partially protected from the direct effects, the indirect effects associated with enhanced UV radiation mainly include an elevated production of oxyradicals both in sea water and in the cell cytoplasm.

Biodiversity

Our knowledge of the Ross Sea and Victoria Land biota is limited to occasional and spatially limited collections, and is thus incomplete. A comprehensive survey is fundamental to the understanding of the biogeography of this area, as well as regional biodiversity. A check-list of the recorded species is available on the web-site www://mna.it.

Data regarding species richness and distribution are available for lichenes, microalgae (lakes, ponds, ice), fungi, protozoans, oligochaetes and insects.

At sea, in the framework of the study of phytoplankton (diatoms and dinoflagellates) and zooplankton studies, protozoans, crustaceans (copepods, euphausids, ostracods, mysidaceans), fish larvae and microzooplankton have been intensively investigated along the western side the Ross Sea.

Within benthic communities, attention was focused, mainly in the area of Terra Nova Bay, on sponges, bryozoans, molluscs, echinoderms and polychaetes.

Among top predators, data are available on diversity, distribution and biomass of fish, birds, mammals in the western Ross Sea.

Particular attention was focused on fish communities, which have been studied also in terms of cytogenetics. Patterns of chromosomal differentiation have been described and interpretation of the karyological data attempted. The monophily of the Notothenioidea is still an unproven hypothesis, that merits further investigations, as phylogenetic data are still limited.

The knowledge of the ecology of seabirds and marine mammals is essential for the management of marine resources and for the assessment of changes due to natural or man made causes. Climate, presence of polynyas, pack ice or fast ice may influence the presence and breeding success of marine mammals and birds.

Along the Victoria Land, data were collected by ship surveys, which gave an important contribution to understand their biogeography, as well as the regional biodiversity. Observations on seabirds (*Pygoscelis adeliae*, *Aptenodytes forsteri*, *Pagodroma nivea*, *Oceanites oceanicus*, *Catharacta maccormicki*) and their breeding locations started to be recorded since 1996/97 summer season.

Progressive Emergence of Benthic Assemblages

At sea, in areas not exposed to disturbance due to anchor ice formation or iceberg scouring, marine benthic communities are typically highly structured by biological interactions. Environmental conditions are relatively consistent, although in coastal benthic systems decadal scale oceanographic variations can result in major shifts in trophic interactions and the structure of benthic communities. Similar to other marine systems, fluxes play an important role in influencing local ecosystem and community structure and functioning. This is clearly illustrated by the role of advected primary production in the structure of coastal benthic communities in McMurdo Sound. These features emphasise the importance of local biotic processes and broad-scale oceanographic variation, the interaction of which are likely to result in environmental gradients markedly different from those apparent in terrestrial ecosystems.

The hypothesis of "polar emergence" has never been tested other than with incidental collections of species which appear to co-occur in the deep sea and shallow Antarctic coastal areas. Recent studies on algal zonation have stressed the disappearance of kelp (occurring in Adelie Land at Dumont d'Urville french station) and the narrower depth distribution of frondose red algae while moving southward from Cape Adare to McMurdo Sound. Similarly, *Adamussium* bed bathymetric distribution shows an up-welling moving from Terra Nova Bay to McMurdo Sound area.

Moreover relevant changes occur in spawning occurrence of this species along the Victoria Land Coast. Finally, being the communities emergence linked to the light availability, the different persistence of ice coverage could, locally, mimic a possible latitudinal gradient.

Working Hypotheses

- **The physical environment**
  The physical measurements needed are:

  1. air, soil, soil moisture, freshwater temperature
  2. solar radiation and UV-B intensity
  3. tide and sea currents vectors and magnitudes
  4. ocean temperature and salinity
  5. topography and bathymetry
  6. sea-ice conditions
  7. wind vectors and magnitudes
  8. lake levels and stream and ice flows

- **Structure and functioning of inland, pelagic (holoplankton and meroplankton), benthic and nekton communities, identifying key species and their ecological relevance (distribution, abundance and role)**
  Biological aspects which could be affected by the latitudinal gradient are:

  1- for communities:
  structure (composition and biomass)
  carbon and nutrient cycles
  variations in primary and secondary productions
  food chains (structure and complexity, feeding guilds etc),

  2- for key species:
  population structure (density, depth/altitudinal distribution)
  changes in trophic needs
  top predators role
  symbiotic relationships
  breeding, reproductive strategy, periodicity and effort
  influence of edaphic parameters (water availability, substrate type etc)

- **Biochemical, physiological and other adaptive responses of key species**
  Adaptive and physiological studies should particularly focus on:

  1- genotypic and phenotypic plasticity
  2- bacterial standing stock, production and enzymatic activity
  3- energy flow in the first compartment of the lower food web
  4- biomolecular adaptations of extremophilics
  5- respiration rates and metabolism in Notothenioidea
  6- adaptive biomolecular mechanisms to small environmental changes
  7- fish citogenetics to evaluate possible chromosomal intraspecific variations and genomic structural changes

- **Xenobiotic compounds, biomarkers and biological indicators**
  Studies will include:

  1- baseline data for POPs in organisms of the Ross Sea/Victoria Land coasts
  2- evaluation of the relationship between the latitude and the type and amount of POPs accumulated by organisms, accordingly to the cold fractionation theory
  3- biomagnification processes and assessment of risk for most exposed species
  4- identification of local sources of pollution (i.e.: scientific stations)

5- assessment of the eventual role of migratory and non migratory habits in the tissue residue pattern
6- identification of sentinel species for biomonitoring studies
7- characterisation of basal biological responses at molecular, cellular and physiological level
8- investigation of the adaptive role of some biological responses and their variability along environmental gradients
9- evaluation of UV-B effects on non marine microalgae

- **Biodiversity**

Biodiversity will be studied at community, species and genetic levels:

1- Community studies will be performed to evaluate:
their distribution
environmental complexity
species richness
functional group diversity
size spectra

2- Species level:
inland taxonomy: lichenes, microalgae, microfungi, protozoans, oligochaetes, collembola, tardigrades;
marine taxonomy: microalgae, macroalgae, protozoans, sponges, cnidarians, annelid polychaetes and oligochaetes, molluscs, crustaceans, echinoderms, fishes

3- Genetic level:
attention will be focused on the population genetic variability of key species (in benthic and pelagic domains) due to the presence of geomorphological or hydrological barriers and, in particular, goals will be:

to extend the analysis of spatial and/or temporal variation at polymorphic loci;
to infer the genetic population structure (in relation to biology);
to estimate the migration rates (in relation to biology);
to test the effect of oceanographic factors on genetic diversity (micro- macro-geographic scale).

Three are the principal investigation sectors:

1. **Atmosphere and environmental gradients**
2. **Inland communities**
3. **Marine communities**

Sector	Research topics	Italian Principal Investigators
Atmosphere and environmental gradients	1. Analysis of climatic time series and of sea-ice coverage; 2. Modelling 3. Planning 4. Synoptic measurements of environmental parameters	**Coppola** (Italian Airforce) Pellegrini **(ENEA)** **Pellegrini** (ENEA-PNRA)

Inland communities	1. Inland and freshwater communities (production, biomass, processes and diversity)	**Andreoli** (Padova Univ.: microalgae biodiversity) **Bargagli** (Siena Univ.: processes in inland vegetal organisms) **Carchini** (Roma Univ: animal biodiversity, biomass, size spectra in freshwater communities) **Ciardiello** (CNR-Napoli: bacterial enzymes) **Fumanti, Cavacini** (Roma Univ.: microalgae biodiversity, UV effects) **Luporini** (Camerino Univ.: ecology and biogeography of ciliate protozoans) **Monticelli** (CNR-Messina: bacterial production)
	2. Sea-birds and marine mammals ecology	**Corsolini** (Siena Univ.: xenobiotic compounds monitoring and toxicity) **Nigro** (Pisa Univ.: bioindicator species, biomarkers) **Olmastroni** (Siena Univ.: ecology of sea-birds and marine mammals) **REGOLI (ANCONA UNIV.: BIOINDICATOR SPECIES, BIOMAKERS)**
Marine communities	1. Water column: production, processes, phytoplankton, zooplankton, ichtyoplankton	**Andreoli** (Padova Univ.: microalgae biodiversity) **Guglielmo** (Messina Univ.: zooplankton distribution) **Monticelli** (CNR-Messina: bacterial production) **Patarnello** (Padova Univ.: krill population genetics) **Povero** (Genova Univ.: organic particulate and dissolved matter) **Sertorio** (Genova Univ.: zooplankton biodiversity) **Vacchi** (ICRAM-Roma: ichtyoplankton distribution and biodiversity)
	2. Benthic communities	**Albertelli** (Genova Univ.: soft-bottom communities) **Bavestrello** (Ancona Univ.: inter-specific relationships) **Cattaneo-Vietti** (Genova Univ.: hard-bottom communities) **Chiantore** (Genova Univ.: trophic and reproductive ecology) **Ciardiello** (CNR-Napoli: bacterial enzymes) **Corsolini** (Siena Univ.: xenobiotic compounds monitoring and toxicity) **Gambi** (SZ-Napoli: ecology and reproductive biology of polychaetes, and ecology of algal) **Luporini** (Camerino Univ.: ecology and biodiversity of protozoans) **Monticelli** (CNR-Messina: bacterial production) **Nigro** (Pisa Univ.: bioindicator species, biomarkers)

		Patarnello (Padova Univ.: benthic population genetics) **Regoli** (Ancona Univ.: bioindicator species, biomarkers)
	3. Fish communities: diversity, ecology, physiological adaptations and phylogenesis	**Di Prisco** (CNR-Napoli: fish adaptations) **Focardi** (Siena Univ.: xenobiotic substances accumulation) **Nigro** (Pisa Univ.: bioindicator species, biomarkers) **Patarnello** (Padova Univ.: fish population genetics) **PISANO (GENOA UNIV.: CYTOGENETICS AND GENOMIC VARIABILITY)** **VACCHI (ICRAM-ROMA: BIODIVERSITY AND DISTRIBUTION)**

Principal investigator	Institution	e-mail address
Giancarlo ALBERTELLI	**UNIV. GENOVA**	albert@dipteris.unige.it
Carlo ANDREOLI	Univ. Padova	labandr@civ.bio.unipd.it
Roberto BARGAGLI	Univ. Siena	bargagli@unisi.it
Giorgio BAVESTRELLO	Univ. Ancona	bavestrello@popcsi.unian.it
Gianmaria CARCHINI	Univ. Roma 2	carchini@uniroma2.it
Riccardo CATTANEO-VIETTI	**UNIV. GENOVA**	catta@unige.it
Paolo CAVACINI	Univ. Roma 1	paolo.cavacini@uniroma1.it
Mariachiara CHIANTORE	Univ. Genova	chiantor@dipteris.unige.it
Pier Francesco COPPOLA	Aeronautica Militare-Roma	pf_coppola@yahoo.it
Simonetta CORSOLINI	Univ. Siena	corsolini@unisi.it
Guido DI PRISCO	CNR-Napoli	diprisco@dafne.ibpe.na.cnr.it
Silvano FOCARDI	Univ. Siena	focardi@unisi.it
Bruno FUMANTI	Univ. Roma 2	Bruno.Fumanti@uniroma1.it
Maria Cristina GAMBI	SZ-Napoli	gambimc@alpha.szn.it
Letterio GUGLIELMO	Univ. Messina	Letterio.Guglielmo@unime.it
Piero LUPORINI	Univ. Camerino	luporini@cambio.unicam.it
Luis MONTICELLI	CNR-Messina	monticelli@talas.ist.me.cnr.it
Marco NIGRO	Univ. Pisa	nigro@biomed.unipi.it
Silvia OLMASTRONI	Univ. Siena	olmastroni@unisi.it
Tomaso PATARNELLO	Uni. Padova	patarnel@civ.bio.unipd.it
Andrea PELLEGRINI	ENEA-PNRA-Casaccia	pellegrini_a@casaccia.enea.it
Eva PISANO	Univ. Genova	pisano@unige.it
Paolo POVERO	Univ. Genova	povero@unige.it
Francesco REGOLI	Univ. Ancona	regoli@popcsi.unian.it
Marino VACCHI	ICRAM-Roma	vacchim@tin.it
Tecla ZUNINI SERTORIO	Univ. Genova	sertorio@dipteris.unige.it

Background of Italian events leading up to the Workshop

The idea to plan a multidisciplinary project focused to evaluate the role of latitudinal gradient on the Victoria Land and Ross Sea communities matured at Terra Nova Bay in the framework of the PNRA project "Structure and dynamics of the coenoses at Terra Nova Bay" between Paul Berkman and Mariachiara Chiantore (austral summer 1998-99). A first proposal was discussed at Bremerhaven during the EASIZ Workshop and Symposium (June 1999).

Further discussions were held in Italy during a workshop organised at the Siena University (with the presence of Berkman) (July 2000) and a first draft was presented at the Accademia dei Lincei (Rome, October 2000).

Guido Di Prisco discussed this project during the 24° SCAR Meeting held in Tokyo (August 2000), while Roberto Bargagli introduced the idea in South Africa during the organisation of the Regional Sensitivity to Climate Change in Antarctic Terrestrial Ecosystems (RiSCC) project which has close affiliations with the Victoria Land project. In fact, in this occasion, it was stressed that "one way of examining the predicted consequences of climate change is to investigate latitudinal gradients as an analogy for future climate change".

RESEARCH INTERESTS IN THE VICTORIA LAND PROJECT BENTHIC COMMUNITIES STRUCTURE AND DYNAMICS

Riccardo Cattaneo-Vietti

Background

The littoral benthic communities distribution inside the Ross Sea, except the McMurdo Sound and Terra Nova Bay are poorly known.

At Terra Nova Bay, communities show a clear zonation according to depth and on the basis of some "guide" species. On hard bottoms, the upper zone, down to 2-3 depth, due to the presence of drifting pack ice, shows a very poor community, mainly composed by cyanobacteria and diatoms and the amphipod *Paramoera walkeri*. From 2-4 m to 70 m depth, the algal communities constitute well defined belts. These algal belts represent shelter and food source for diversified and abundant vagile fauna, among which the echinoid *Sterechinus neumayeri* and the asteroid *Odontaster validus*. Below, at 70-120 m depth, a complex community of sponges and anthozoans characterises the rocks, reaching high values in biomass and species richness.

The soft bottoms generally start at 20-30 m depth and are constituted by coarse sands and gravel where *Alcyonium* sp. is often found. Herein the communities are characterised by bivalves (*Laternula elliptica, Yoldia eightsi, Adamussium colbecki)* and polychaetes (*Tharyx cincinnatus*, *Aglaophamus ornatus, Spiophanes tcherniai, Leitoscoloplos mawsoni).* Much deeper, on muddy sands at about 150 m depth, the polychaete *Laonice weddellia* characterises the community and brachiopods can be found on small gravel.

The great heterogeneity of the bottoms contributes to create a mosaic structure of the communities that, also due to the stable environment, can reach higher values of species richness and biomass.

Interests

- ✓ Evaluation of the distribution of the main communities found in Terra Nova Bay along the Victoria Land Coast
- ✓ Test the hypothesis of polar emergence
- ✓ Quali-quantitative evaluation (biomass) and key species identification and role
- ✓ Relationships between organisms and substrates (grain size, mineral composition and lithology)

RESEARCH INTERESTS IN THE VICTORIA LAND PROJECT ECHINODERM AND MOLLUSC POPULATION STRUCTURE, REPRODUCTIVE ECOLOGY, AND ITS CONSEQUENCE IN POPULATION ISOLATION

Mariachiara Chiantore

Background

Molluscs and echinoderms are widespread marine organisms, often playing a key-role in benthic community structure and dynamics.

They can reproduce applying quite different larval strategies in order to cope with environmental and biological constraints.

Three are the most common reproductive strategies:

1) planktotrophic pelagic larvae
2) lecitotrophic larvae
3) brooding

The study of larval and juvenile ecology of marine invertebrates offers opportunities to explore how organisms interact with their environment. What happens to these early stages in their environment may be essential for determining patterns of life cycle evolution, current patterns of population dynamics and population genetic isolation.

Interests

- ✓ Evaluation of reproductive effort of Antarctic echinoderms and molluscs
- ✓ Evaluation of the role of environmental parameters in affecting reproductive effort and timing along the latitudinal gradient
- ✓ Influence of food availability and temperature on growth rates
- ✓ Estimation of energetic variations in body tissues at different times and in different experimental conditions
- ✓ Larval strategy and influence of environmental factors

LATE-HOLOCENE GLACIAL CONDITIONS IN THE ROSS SEA EMBAYMENT

Howard Conway

Changing glacial environments have had major impacts on the evolution of Antarctic biota (Clarke and Crame, 1989; Chen et al., 1997), and as a consequence, much of what is known about the glacial history of Antarctica has been inferred from fossil biota found in geologic deposits (Berkman et al., 1998).

The Ross Sea Embayment is a proven, rich source of terrestrial and marine proxies that have enabled reconstructions of climate and glacial conditions during the Holocene (Figure 1 shows an example); additional studies are needed to improve the spatial and temporal resolution of these unique data. Such high-resolution data are needed to help answer questions concerning the stability of the marine-based West Antarctic Ice Sheet (WAIS), the stability of the East Antarctic Ice Sheet, and the phasing of climate changes in Antarctica and the North Atlantic.

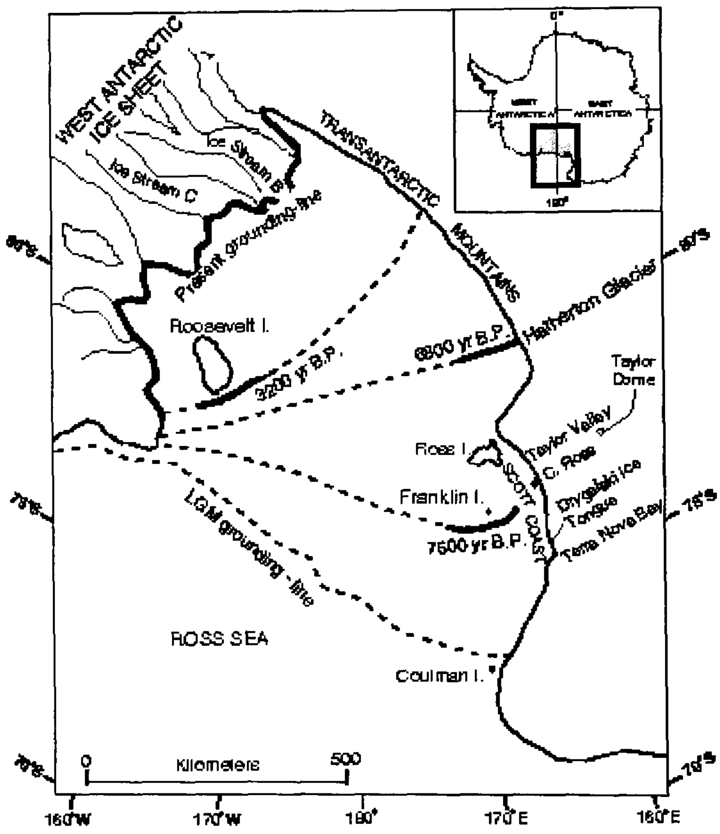


Figure 1: Holocene grounding-line recession in the Ross Sea Embayment. Adapted from Conway et al, (1999). Map shows dated locations used to resolve grounding-line retreat in the Ross Sea Embayment: (i) Marine evidence, including seismic reflection profiles and dated sediment cores, indicates that grounded ice extended almost to Coulman Island during the LGM (Licht et al., 1996, 1999; Shipp et al., 1999). (ii) ^{14}C dates of lacustrine algae from proglacial lakes (Hall et al, 1999, 2000), molluscs from sediment cores (Licht et al, 1999) and organic material contained within raised beaches (Hall and Denton, 1999) all indicate grounding line retreat past McMurdo Sound about 7600 yr B.P. (iii) ^{14}C dates of algae from ice-dammed lakes indicate grounding line retreat past the Hatherton Coast about 6800 yr B.P. (Bockheim et al, 1989). (iv) Measurements of the internal stratigraphy (from radio echo-sounding) and surface velocity (from repeat GPS surveys of poles) used in a model of ice cap evolution, indicate the grounding line was still north of Roosevelt Island about 3200 years ago.

Additional studies are needed to help resolve ambiguities in the present data that pertain to the timing of recession from the LGM position to Franklin Island (Baroni and Orombelli, 1994). Recent finds of seal-skins and shells contained in raised beaches in Terra Nova Bay (Brenda Hall, pers com, 2001) will help resolve the timing of retreat in this region. Studies are also needed to better define the retreat south of the Hatherton Coast. During the LGM, the outlet glaciers that now drain East Antarctic ice through the Transantarctic mountains (eg. Reedy, Beardmore, Shackelton, Reeves and Campbell Glaciers) were dammed by grounded ice in the Ross Sea. Cosmogenic dates from exposures along the margins of these glaciers would help define the retreat history of the WAIS.

The structure and thickness of past configurations of the WAIS is unknown; the dynamics of the Ice Sheet today is dominated by fast-flowing ice streams but it is not known whether the ice streams were active during the LGM and the early Holocene. Geophysical measurements, including radio echo-sounding, ice cores, and paleo-thermometry, from key locations such as Ridge AB, Roosevelt Island, Crary Ice Rise, Wilson Piedmont and Talos Dome are needed to help reconstruct past configurations and define the preset rate of thinning and stability. Models of post-glacial rebound (constrained by dated raised beaches and records of global sea level) would also help resolve this issue by providing an estimate of the total ice volume during the LGM.

Advance and retreat of the WAIS has generally followed glacial-interglacial cycles; the timing of retreat, after most of the sea-level rise from melting of Northern Hemisphere ice sheets had occurred (Peltier, 1998), suggests that its recession was triggered by rising sea level. In contrast, the small alpine glaciers in the McMurdo Dry Valley region (including Taylor Glacier) generally retreat during glacial times (probably because of the decreased accumulation) and advance during interglacial times. Ablation now occurs primarily by sublimation, although some melting below about 1500 m in elevation provides the main source for streams that run intermittently during the late-summer (Chinn, 1986); rates of ablation $\dot{b}$ at the termini are typically 0.3 to 0.4 m/yr. For a glacier that experiences a small change in mass balance, the characteristic response time to reach a new steady state at the terminus can be approximated by $H / \dot{b}$, where H is the maximum thickness. The time constant for the Dry Valley glaciers is ~1000-2000 years; these glaciers should now be fully adjusted to the accumulation increase that occurred at Taylor Dome at the glacial-interglacial transition (Steig et al, 2000). This is consistent with modern measurements that indicate the mass balance of most of the Dry Valley glaciers is now near zero (Chinn, 1980, 1986). However maps of margin morphology show more extensive moraines around most of the alpine glaciers in the past (Hall et al, 1993). For example a complete moraine loop (Alpine II) extends about 1 km in front of the modern terminus of Meserve Glacier (Hall et al, 1993). A simple, steady-state calculation indicates that the annual mass balance would have to be about 2 cm/yr more positive than present for the glacier to reach this position, suggesting the possibility of either a slightly wetter climate (about 50% wetter) and/or less ablation during the last interglacial. More rigorous mass balance calculations and flow-line and models of the alpine glaciers are needed to improve understanding of the climate and glacial history of the McMurdo Dry Valley region.

ECOTOXICOLOGY AND ECOPHYSIOLOGY

1) Simonetta Corsolini, Silvia Olmastroni and Silvano Focardi
2) Marco Nigro and Francesco Regoli

1)

Remote areas including the Polar regions were considered to be pristine until contamination was first documented in the 1970's (Risebrough *et al.*, 1968; Risebrough *et al.*, 1976).

Global contamination by persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs) and organochlorine pesticides has been well documented (Tanabe *et al.*, 1986; Iwata *et al.*, 1993; Focardi *et al.*, 1995; Corsolini *et al.*, 2000). Oceans are a major sink for persistent chemicals, which are transported from continental areas by atmosphere and oceanic currents (Loganathan *et al.*, 1991; Loganathan *et al.*, 1993). Global distillation or fractionation by condensation in cold polar environments has been proposed as a mechanism whereby the polar regions may become sinks for some POPs (Wania *et al.*, 1993) (Figure 1). They vaporize from source areas in the mid-latitudes and are transported to the high latitudes by air mass movements. In relation to the volatility of the various POPs, they condense at different ambient temperatures and fall out on the earth surface again (Wania *et al.*, 1994). Condensation and falling out depend on physicochemical properties of molecules and air temperature so chemical deposition is strictly correlated to them and the process has been defined as "global distillation". This is why it is expected that the presence of POPs may follow a latitudinal gradient. Due to the low temperatures, POPs degradation is very slow in the polar regions. Ice is a cold trap for POPs and it can release them thus these compounds may enter in the trophic webs where they bioaccumulate and biomagnify. Migratory animals, especially top predators (such as South Polar skua and other birds, whales), may be another source of pollutants with their excrements and carcasses.

The Southern Ocean isolates Antarctica from other oceans and lands therefore volatile contaminants can reach it mainly via the transport of air mass. Furthermore, the southern hemisphere is mainly occupied by oceans and land is relatively less populated than the northern hemisphere so that the contamination pattern from the Northern high latitudes to the Southern high ones follows a latitudinal gradient (Tanabe *et al.*, 1984; Wania *et al.*, 1994).

Most volatile compounds are expected to be transported to the poles. Among POPs, polychlorinated biphenyl (PCBs), polychlorinated-dibenzo-*p*-dioxins (PCDDs), polychlorinated-dibenzofurans (PCDFs), polychlorinated-naphthalenes (PCNs) and chlorinated pesticides (i.e. *p,p'*-DDE) have already been detected in Antarctic organisms (Focardi *et al.*, 1993; Focardi *et al.*, 1995; Corsolini *et al.* 2000a; Corsolini *et al*, 2000b) (Figure 2). All these compounds are industrial chemicals that exhibit several common properties such as high lipophilicity (increasing with chlorination), high stability to breakdown by acids, bases, heat, hydrolysis. Their characteristics contributed to their wide use in industry and agriculture and as well as to their accumulation in ecosystems. Moreover, they elicit toxic responses in organisms including humans (Safe, 1990; Kashimoto *et al.*, 1981; Ryan *et al.*, 1993).

A latitudinal gradient approach may provide a useful and new tool to answer to several questions:

- are the latitudinal and consequent temperature gradient important factors in the bioaccumulation of global contaminants?
- are the scientific stations a local source of pollution?
- do animal migratory or non migratory habits affect the presence of POPs in the tissues of marine organisms?

Expectations include:

- the possibility of evaluating the relationship between the latitude and the type and amount of POP accumulated by organisms, accordingly to the cold fractionation theory;
- provide baseline data for the mentioned POPs in organisms of the Ross Sea/Victoria Land coasts;

- outline the biomagnification processes in the Antarctic trophic webs and identify the most exposed species by evaluating xenobiotic toxicity (using the 2,3,7,8-tetrachlrodibenzo-p-dioxin Toxic Equivalents approach, TEQ; Safe, 1990; Van den Berg *et al.*, 1998).

Tissues of invertebrates, fish, seabirds, marine mammals will be used for the mentioned purposes; non-invasive method will be preferred (i.e.: bleeding, unhutched egg collection, biopsies).

Marine birds and mammals - Data on the ecology of seabirds and marine mammals are essential for the management of marine resources and accurate assessment of changes due to natural or man made causes. Climate, presence of polynyas, pack ice or fast ice may influence the presence and breeding success of marine mammals and birds (Stirling, 1997 ; Ensor, 1979 ; Ainley and LeResche 1973; Ainley *et al.*, 1998; Ainley *et al.*, 1998).

Literature reviews (Woehler, 1993; Croxall *et al.* 1995) on data available on seabirds species represent a good statement of the populations but some data were collected many years ago (see data on *Pagodroma nivea* in the Ross Sea in Croxall *et al.*, 1995). Ship surveys made in the past (Ainley, 1984; Ainley, 1985; Saino and Guglielmo, 1999) gave an important contribution to understand the biogeography of the Ross Sea, as well as regional biodiversity. Nevertheless in some areas data on the presence of the biota is limited to random collections while a species inventory will be fundamental to improve our knowledge of the Ross Sea species.

The monitoring of marine birds and mammals along Victoria Land Coastal Transect can be carried out in the framework of Adélie penguin monitoring research. The proposal is based on 7 years of biomonitoring and documentation of penguin and skua nesting near the Italian Base of Terra Nova Bay. Observations on seabirds (*Pygoscelis adeliae*, *Aptenodytes forsteri*, *Pagodroma nivea*, *Oceanites oceanicus*, *Catharacta maccormicki*) and their breeding locations started to be recorded since 1996/97 summer season. During 2000/01 summer season helicopter surveys were performed from Inexpressible Island to Cape Hallett to visit seabirds breeding areas and penguin colonies; when possible ground counts or estimation was performed. A group of about 20 *Orcinus orca* as well as about 10 *Balaenoptera acutorostrata* were sighted regularly visiting the polynya of Terra Nova Bay next to Cape Washington. More than 200 *Leptonychotes weddelli* were estimated to rear pups next to Gondwana Station (Terra Nova Bay), and more than 100 in the Wood Bay; *Hydrurga leptonyx* was sighted foraging on penguins at Inexpressible Island and Adélie Cove.

To understand the distribution and ecology of seabirds and marine mammals along the Victoria Land Coastal High Latitudinal Gradient the following informations are to be collected:

- population and density estimation
- nesting/nursery sites locations
- census and mapping of reproduction sites by using: aerophotography; visual counts, GPS and GIS elaboration of data
- environmental factors which may affect species distribution (seaice conditions, climate)

2)

The Antarctic marine environment is considered pristine. However, the long distance transport of air borne chemicals (such as some persistent organic pollutants), the impact of increasing levels of UV radiation (due to the stratospheric ozone depletion) and focal sources of physical-chemical disturbance associated with scientific bases and tourism depict the opportunity of developing integrated ecotoxicological studies.

The use of key species as sentinels (bioindicators) for monitoring environmental changes around Antarctica has been stressed by SCAR programs, such as EASIZ. However, very limited investigations have dealt with the development and validation of biomarkers in Antarctic organisms, based on responses at different level of biological organization, for early detection and prediction of environmental changes (Jimenez et al 1999; Regoli *et al.*, 1997; Regoli *et al.*, 1998). Thus it appears to be a significant issue to be addressed the improvement of our knowledge about the biochemical, molecular, genetic and physiological responses to a changing environment along a north - south continuum.

Among the numerous biological responses described as biomarkers in the last two decades, those based on the cellular antioxidants and on the susceptibility to oxidative stress are of increasing interest for ecotoxicologists since several physical and chemical perturbations are known to exert their toxic effects through the enhancement of intracellular generation of reactive oxygen species. Antioxidant defenses of Antarctic key species were shown as useful biomarkers for detecting pollutant effects under both field and laboratory conditions; moreover, variations of the redox status appeared closely related to other important damages including lysosomal membrane destabilization (Regoli *et al.*, 1997; Regoli *et al.*, 1998; 1 Regoli *et al.*, 999). The antioxidant system is also strictly involved with the impact of UV radiation on biota. In fact, despite many invertebrates are partially protected from the direct effects, the indirect effects associated with enhanced UV radiation mainly include an elevated production of oxyradicals both in sea water and in the cell cytoplasm (Regoli *et al.*, 2001).

The rationale for promoting ecotoxicological studies, based on a biomarker approach, in the framework of the Victoria Land Coasts Project includes the opportunity to address the following issues:

- identification of the more appropriate species to be selected as bioindicators in benthic communities along the latitudinal transect,
- characterization of their baseline levels for both chemical pollutants and biological responses selected as biomarkers
- investigate the effects of enhanced UV radiation on biota along a North - South gradient,
- study the influence of natural factors, such as trophic condition and the persistence of sea ice cover, on biological responses (biomarkers)
- evaluate the biological relevance of impacts associated with scientific bases.

The species to be used for such studies should have a wide distribution along the study area, and possibly around Antarctica, such as bivalve mollusks, sea star, sea urchins and/or some species of fish.

The biomarkers will be selected among the followings:

- stability of biological membranes with emphasis to lysosomes,
- variations in the levels of the main antioxidants,
- susceptibility to oxidative stress by Total Antioxidant Capacity,
- levels of metallothioneins,
- activity of cytochrome P-450,
- occurrence of genotoxic damage

Associated web sites

http://irptc.unep.ch/pops/indxhtms/asses0.html

http://www.eces.org/articles/static/976428000697 11.shtml

http://www.planetark.org/dailynewsstory.cfm?newsid=6727&newsdate=18-May-2000

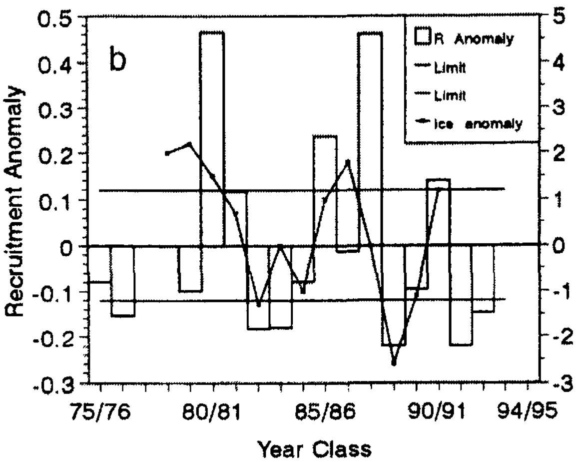
http://www.epa.gov/ncea/pdfs/dioxin/dioxreass.htm

VARIABILITY IN THE TROPHIC ECOLOGY OF THE ROSS SEA: LINKING MODERN VARIABILITY TO SIGNALS IN THE FOSSIL RECORD

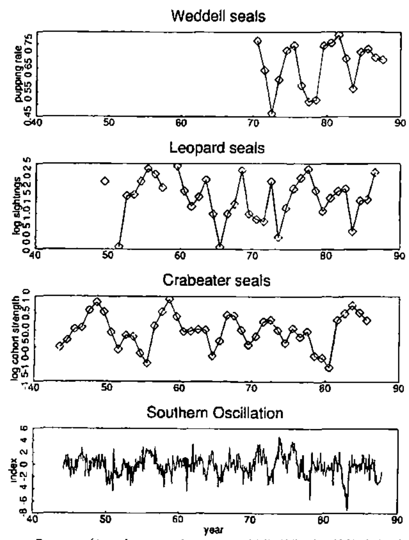
Daniel P. Costa

The Victoria Land initiative is an exciting program that will integrate processes at unprecedented levels of scale. A major challenge will be to discover ways of integrating processes at the diverse and possibly disparate levels of scale as proposed for the Victoria Land Program. Nonetheless there have been many advances in the last decade with respect to our ability to examine the connection between climate driven processes and the structure of marine communities. While early work focused primarily on basic distributions and predator prey interactions, more recent work has examined the role of physical processes as a causal factor in inter-annual variations in distribution, abundance and reproductive performance of marine organisms. Studies have shown that much of the inter annual variation is coupled with changes in environmental features or physical processes that limit where organisms can go or how effectively they can forage. A variety of international programs are examining this bio-physical coupling, with respect to upper trophic levels the most notable is GLOBEC, (Global Ocean Ecosystems Dynamics, http://cbl.umces.edu/fogarty/usglobec/). Southern Ocean GLOBEC is centered along the Western Antarctic Peninsula region in the vicinity of Marguerite Bay (http://www.ccpo.odu.edu/Research/ globec_menu.html). An underlying premise of GLOBEC is that physical processes that force biological interactions structure marine communities. These physical processes are tied to climate and thus allow a predictive understanding of the bio-physical coupling over wide spatial and temporal scales (Roemmich and McGowan 1995, Markgraf et al. 2000).

The importance of the physical environment in high latitude ecosystems has been recognized for some time. The reduced complexity of polar communities makes them more tractable and holds the promise that we may be able to unravel the linkages between biological and physical processes. Nonetheless, given the history of this region it is surprising how little we know about the marine food web, especially compared with other regions of the Antarctic such as the Weddell Sea or the Antarctic Peninsula (Eastman and McCune 2000). What is known suggests that similar to other regions of the Antarctic, the food chain is based predominately on krill, either *Euphausia superba* or *Euphasia crystallorophias* along with the Antarctic Silver fish *Pleuragramma antarcticum*. An important feature of the Ross Sea is that it is predominately a deep continental shelf habitat. This limits the region to species associated with continental shelf habitats. The constant cold water (< -1.5 ° C) further limits the inhabitants to those that are freeze resistant. Fish of the Family Nototheniidae are uniquely capable of inhabiting this cold environment due to the presence of a special antifreeze glycopeptide. As a result 54 of 80 species reported for this region are from this family (Eastman and McCune 2000). As the Antarctic silverfish is the dominant species in water column of the Ross Sea it is common in the diet of mid-water feeding species such as Weddell seals, Ross seals and Emperor penguins (Kooyman and Kooyman 1995, Cherel and Kooyman 1998). In contrast shallow diving species such as Adelie Penguin, Crabeater seal and minke whale, consume one of two species of krill. *E. superba* tends to be more common near the continental slope, while *E. crystallophorophias* predominates along the coastal margins and in the more southern reaches of the Ross Sea. However, recent research on the distribution of krill in the Ross Sea suggests that we have much to learn as to the actual distribution let alone the factors responsible for it's distribution (Azzali & Kalinowske 2000).



While our understanding of krill dynamics in the Ross Sea is limited, we know that seasonal pack ice is essential for krill production. We know that *E. superba* grazes on under-ice algae in the winter and relies on the algae blooms associated with the spring break up and melt (Siegel and Loeb 1995). Krill abundance and recruitment is tightly correlated with the extent and timing of the seasonal pack ice, especially in the area of the Antarctic Peninsula (Loeb et al. 1997). The extent of the pack ice is related to a complex number of factors, but is correlated with average air temperature in the region. Variation in the extent of annual sea ice propagates in what is known as the Antarctic Circumpolar Wave (ACW). The ACW has a period of 4 yrs and a wavelength of 11,000 km and is influenced by the El Niño Southern Oscillation (White and Peterson 1996).



Time series of (top to bottom) reproductive rates of adult Weddell seals in McMurdo Sound, $\log_{10}$ numbers of leopard seals seen annually on Macquarie Island, and relative strengths of crabeater seal cohorts estimated from collections made in the vicinity of the Antarctic Peninsula

Given the importance of sea ice to the prey of APEX predators it should not be surprising that variations in the abundance or reproductive success of APEX predators follows sea ice patterns (Fraser et a, 1992). For example, the recruitment or cohort strength of Antarctic pack ice seals shows considerable interannual variation that correlates with the ENSO index (Testa et al. 1991).

More recently, Fraser et al. (1992) and Smith et al. (1999) have argued that changes in the penguin populations in the Antarctic Peninsula are associated with long-term changes in the persistence and extent of seasonal sea ice. Adelie penguins are at the northern limit of their range and in some locations overlap with Chinstrap penguins. During the winter Chinstrap penguins forage in open water, while Adelie penguins forage in the pack ice. In the Peninsula recent warming trends favor Chinstrap penguins. Whereas, in the Ross Sea where Adelie penguins are at the southern limit of their range, the warming trend appears to be causing an increase in their numbers.

Considerable data exists to indicate strong associations between environmental variables (ice extent, wind stress, etc) and the Antarctic food web. However, the specific details of how these interactions occur are poorly understood. Fortunately, there are a variety of approaches that will allow us to examine these processes with respect to what drives these associations today as well to how they might have changed in the past. For example, the foraging behavior of seals, penguins and whales can be remotely tracked with specialized instrument that can record their diving behavior and location (Costa 1993, (Kooyman and Kooyman 1995). These data can be correlated with information on sea ice patterns (Watanuki et al. 1993), krill distribution (Croll et al. 1998) and reproductive performance (Kooyman 1993). Variation in the C and N isotopes of both modern and ancient organisms can provide insight into the diet or changes in diet that relate to the trophic level consumed (Rau et al. 1992). Changes in the distribution of abandoned ancient and modern Adelie penguin rookeries coupled with isotopes studies may provide insight into how conditions may have changed (Baroni and Orombelli 1994, Emslie et al. 1998).

SOME ITALIAN RESEARCH INSTITUTIONS AND PI'S INTERESTED IN PARTICIPATING IN THE VICTORIA LAND TRANSECT PROJECT

Guido di Prisco

Institute of Protein Biochemistry and Enzymology, CNR, Naples, Italy (PI: G di Prisco)

The research spans in several fields comprising physiology and biochemistry of terrestrial and marine organisms, both vertebrates and invertebrates, which have colonised the Antarctic environment: fish, birds, seals, extremophilic microorganism (thermophiles and psychrophiles).

- **Fish** (G di Prisco and co-workers). Some of these studies have been carried out for 20 years, before the inception of PNRA, and have been addressed to the molecular bases of fish biochemical and physiological adaptations to the low environmental temperatures, in order to establish correlations with the framework of ecological constraints and – more in general – with the mechanisms of evolution. Research on cold adaptation has been essentially aimed at studying two biological systems of primary importance:
    1. *Respiration* (oxygen-transport and storage system). The main target of these studies is hemoglobin (Hb), the oxygen-carrying protein. Hb has been characterised in about half the species of the dominant suborder Notothenioidei and in species of other suborders (e.g. Zoarcoidei), from the structural and functional points of view, paying special attention to *(i)* thermodynamics of oxygen binding; *(ii)* three-dimensional crystallographic structure in two species whose Hbs have highly similar amino acid sequences but are functionally very distinct; *(iii)* organisation and arrangement of globin genes and transcriptionally inactive gene remnants of icefishes. From this and many other points of view, at present notothenioids are in absolute terms the most thoroughly characterised group of fish in the world. Their importance as a reference group for teleosts of other latitudes is undisputed.
    2. *Metabolism* (enzyme systems of key metabolic importance: erythrocyte glucose-6-phosphate dehydrogenase, liver L-glutamate dehydrogenase, muscle phosphorylase, blood and gill carbonic anhydrase. The relationship between molecular structure and catalytic behaviour has been investigated in relation to cold adaptation, especially considering the thermodynamic response to temperature and pressure variations. Some enzymes are studied in relation to the different physiology of red-blooded species and of species whose blood is devoid of Hb (icefish).

Extremophilic microorganism: thermophiles, alophiles and psychrophiles (G di Prisco, M Antonietta Ciardiello).

Several species of thermophiles (one of which, *Bacillus thermoantarcticus*, is a novel species) and alophiles have been isolated from Mount Melbourne and Edmonson Point. Taxonomical work has been carried out, as well as characterisation of enzyme content and membrane lipids. A psychrophile (*Psychrobacter* sp. TAD1) has been isolated from fresh continental water. Two glutamate dehydrogenases, each specific for either NAD or NADP, have been purified and characterised, with respect to cold-adapted features. The NADP-dependent enzyme has been overexpressed in *Escherichia* coli; the complete amino acid sequence has been established.

Aims of participation in the Victoria Land Transect Project

The Project, foreseeing action within 6-7 degrees of latitude in the Ross Sea, tackle several topics highly pertinent to our research, especially as far as distribution and biodiversity of the species is concerned, as a function of (i) environmental dynamics and chronologies; (ii) effect of sea-ice cover; (iii) effect of gradients of physico-chemical parameters along the transect; etc.

The systematic character of the Project activities will give us the opportunity to considerably increase our knowledge on respiration and metabolism of Notothenioidei, as well as to continue the studies on an expanded range of microbial species from land and sea (*see Monticelli*). Moreover, monitoring *(i)* the distribution of species along the transect and *(ii)* the fine response of fish adaptation mechanism to small physico-chemical variations in the environment (*see Eastman and co-workers*), integrated with cytogenetic studies and phylogeny (*see Pisano and co-workers*), is an essential step to continue our efforts aimed at understanding evolution also at the molecular level, and above all to tackle other general aspects of the utmost importance, such as climate changes, biodiversity, anthropogenic impact on the environment, the effect of the enhancement of UV-B radiation due to ozone depletion on fish larvae (as an example) which often prosper at the water surface, etc. These aspects are tightly linked to Global Change: a dramatic phenomenon bound to become more and more crucial for the survival of mankind.

At the SCAR WG of Biology (Tokyo, 2000) it was stressed that the Project is correlated with other important international programmes, such as EASIZ, EVOLANTA and ICEFISH, some of which are SCAR-sponsored. Our research teams are deeply involved in all of these programmes.

1. **Dept of Experimental, Environmental and Applied Biology, Univ of Genova, Italy (PI: Eva Pisano)**
and
2. **National Museum of Natural History, Paris, France (PI: Catherine Ozouf-Costaz)**

Our studies are focussed on Cytogenetics of Notothenioid fishes. The main aim is the acquisition of genomic structural information by way of conventional and molecular cytogenetics, in order to (*see Eastman and co-workers; di Prisco and co-workers*):

- contribute to the knowledge of fish biodiversity
- evaluate possible chromosomal intraspecific variations among populations of most common species along the latitudinal gradient
- correlate genomic structural changes with main adaptive processes in the evolution of notothenioid fish

3. **University of Padova, Italy (PI: T Patarnello)**

One of the current Antarctic research interest is the analysis of inter- and intra-specific genetic diversity in **finfish** and **krill** species. Investigations have been carried out by means of molecular markers such as sequence polymorphism at mitochondrial DNA, amplified fragment length polymorphisms (AFLPs) and microsatellite nuclear loci. The results indicate the existence of distinct genetic pools in the different areas of the Southern ocean for both fish and krill species. Such genetic heterogeneity is more pronounced in the two fish species (*Pleuragramma antarcticum* and *Chionodraco* spp.) as compared to the Antarctic krill *Euphausia superba*. In both fish and krill spatial as well as temporal genetic heterogeneity was evidenced. Our goals are: *1)* to extend the analysis of spatial and/or temporal variation at polymorphic loci; *2)* to infer the genetic population structure (in relation to biology); *3)* to estimate the migration rates (in relation to biology); *4)* to test the effect of oceanographic factors on genetic diversity (micro- macro-geographic scale).

The species on which we intend to focus are: *E. superba* (Antarctic krill); *E. crystallorophias* (ice krill); *P. antarcticum* (Antarctic silverfish); *Chionodraco* spp (icefish).

Molecular markers currently developed and routinely in use for the above listed species are:

- sequence polymorphism at hypervariable mitochondrial DNA loci
- amplified fragments length polymorphism (AFLPs)

length polymorphism at variable number tandem repeat (VNTR, microsatellite) nuclear loc.

RESEARCH INTERESTS IN RELATION TO VICTORIA LAND TRANSECT

Peter T. Doran

My research interests for the Victoria Land workshop would be to test conclusions gained through involvement in the McMurdo LTER for their broad applicability to the coastal region. This would include research on micrometeorology, hydrology, and modern lacustrine processes, how they are impacted by global change, and how they relate to sedimentary deposits. Much of this work centers around the concept of legacy and its role in shaping the present terrestrial ecosystem. The term "legacy" refers to the carry-over or "memory" of the ecosystem of past events. A climatic legacy strongly imprints current ecosystem functions at MCM, including inundation of the entire Taylor Valley by Lake Washburn during the late Pleistocene, and a subsequent cold, dry period ending about 1000 yrs BP . Does this concept of legacy apply outside of the McMurdo Dry Valleys? In order to address this question in the transect we will need a strong climate/paleoclimate component to the research.

We should consider that imbedded in the terrestrial component of the latitudinal transect will be an altitudinal gradient. The map defining the gradients in the transect concept (Figure 1 in the original invitation), does not include elevation, yet the Victoria land coast is very rugged and much of the terrestrial ecosystem will be well above sea level, even within short distances to the coast. In fact, there may be as much change in precipitation and temperature along a altitudinal transect at one latitude, as we would expect to find along the latitudinal transect of the entire coast near sea level. As an example Figure 1 is mean annual temperature vs elevation for a number of dry valley meteorological stations operated by the LTER. Mean annual temperatures range more than 10 degrees, as a function of not only altitude, but as a function of exposure to katabatic wind, which is partly controlled by topography and partly by air mass interactions. Based on this we can not extrapolate climate conditions from the coast to higher elevations by assuming that the dry adiabatic lapse rate will apply. Existing meteorological stations (AWS) will not define the terrestrial climatic regime well enough. A key component of the transect will be the establishment of a dense meteorological monitoring network at several locations along the transect. This should include precipitation collection was is currently lacking in autonomous meteorological networks. Recent system development should allow this to be done in the coastal environments where snowfall amounts are measurable.

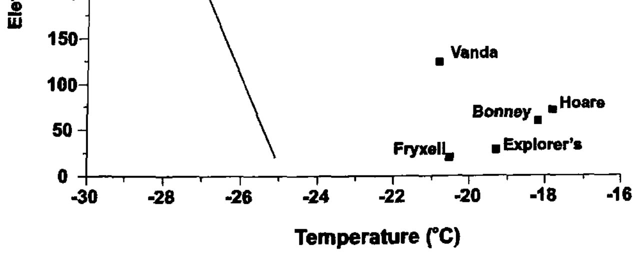


Figure 1: mean annual temperature vs elevation in the McMurdo Dry Valleys. the solid line represents the dry adiabatic lapse rate centered on Lake Vida

The opportunity to carry out a coastal hydrology campaign is significant. Current estimates of the contribution of Antarctica to sea level change due to climate warming are that it will contribute negatively to sea level rise. This is due to the combined facts that glacial melt is thought to be a minor component of the continental water budget, and that increased precipitation on the continent will be increase. However, it is not clear that we know this to any degree of certainty. A transect like the one proposed could increase by orders of magnitude what we know about the amounts of glacial melt coming off of the continent. Quantifying the annual variation in stream flow coming off the coast will further allow for calculations of the marine impact of varied freshwater input. During periods of climatic deterioration where we have records of extreme desiccation in the dry valleys (e.g. prior to 1200 yr BP), we might expect less (or no) freshwater input to the coastal marine system, causing increased salinity and resultant ecosystem shifts. Stream flow can be measured autonomously, but requires frequent site visits during the flow season for calibration.

Other physical monitoring techniques that should be applied and can be done by autonomous instruments (that could be left at sites to broadcast data via satellite), include stream flow, soil temperature, lake levels, ablation, underwater light, and lake water temperature fluctuations. Lake levels can be recorded continuously using pressure transducers, anchored to the lake bottom. The LTER has recently devised a technique for continuously measuring ablation from the lake surface using a second pressure transducer suspended in the lake from the ice cover. Use of this technique requires that the lake not be frozen to it's bed. This technique could also be used in coastal multi-year sea ice to measure coastal ablation rates. The LTER also routine measures lake temperature to within 0.02°C at multiple depths continuously, which yields important information on mixing processes.

Before any conclusions can be drawn about past environments from e.g. sediment cores, the modern systems need to be well-defined. For instance in the dry valley lakes, $\delta^{13}C$ and $\delta^{15}N$ in sediment cores varies less than in the surface sediments of the modern lakes. We discovered (Doran et al. 1998) that much of the variation in the $\delta^{13}C$ is depth controlled. Shallow water benthic communities (including moats and shallow ponds) have such high rates of photosythesis that a diffusion limitation is set up where the communities essentially get starved for CO_2 with ^{12}C (their preference) and they are forced to use more ^{13}C. The result is a $\delta^{13}C$ signature that is heavier in shallow waters, and light in deep. This trend then helps us to determine the significance of changing $\delta^{13}C$ signatures in sediment cores. I would propose that besides characterizing the modern environment for community structure, that we fully characterize the modern environment for processes that control the biogeochemistry, particularly that which is preserved in sediments (e.g. biomarkers). Only then can we collect samples and decipher paleoecological changes in a logical way. Paleoenvironments in the terrestrial ecosystem can be defined through the use of fossil lacustrine and fluvial deposits which contain preserved organic material, and other proxies. Any water bodies encountered could be cored to retrieve potentially long-term records of ecosystem change.

Links

My web site: http://tigger.uic.edu/~pdoran/home.htm
LTER web site: http://huey.colorado.edu/
VALMAP GIS: http://bonney.sr.unh.edu/
MSSS website: http://barsoom.msss.com/earth/antarctica/marypbs/marypbs.html

DOCUMENTING LATITUDINAL AND DEPTH GRADIENTS FOR FISHES ALONG THE VICTORIA LAND COAST

Joseph T. Eastman

My interest in the Victoria Land Project centers on the diversity and distribution of fishes along latitudinal gradients and at possible faunal breaks or transition zones in the Ross Sea. I have experience trawling for and identifying fishes from the Ross Sea. A species list of Ross Sea fishes is included as Table 1.

Background

Certain components of the Antarctic fish fauna, especially the endemic notothenioids, are sufficiently well known from taxonomic and zoogeographic perspectives that they could be employed in an environmental variability project. The fauna of the shelf and upper slope of the entire Antarctic Region is relatively small and unusual in composition, consisting of 213 species with higher taxonomic diversity restricted to only 18 families. Three groups compose 88% of the Antarctic fauna – 96 species of perciform notothenioids, 67 liparid snailfishes and 23 zoarcid eelpouts. With reduced competition from other fish groups, notothenioids evolved considerable morphological and ecological diversity and, although a benthic group, they occupy niches in the water column. In High Antarctic shelf areas, where the fauna is less than 100 species, notothenioids are overwhelmingly dominant, comprising 77% of the species and 90-95% of fish abundance and biomass. Compared with Low Antarctic shelf regions, fish species diversity is greater in the High Antarctic but biomass is 10-20 times lower. The increasing speciosity with latitude may be attributable to the fact that the High Antarctic shelf is a unique evolutionary site holding a species flock of notothenioids (Eastman and McCune, 2000). With the recent discovery of many new species, the Liparidae is now the most speciose family of Antarctic fishes. Unlike notothenioids, little is known about their ecology and distribution. The Zoarcidae are opportunistic – they have evolved antifreeze and are found at both poles as well as in most intervening oceanic areas. They are also the only fish group consistently found at hydrothermal vents.

The Ross Sea fauna

The Ross Sea is one of the largest areas of the Antarctic continental shelf and representative of the High Antarctic Zoogeographic Zone. Fishes have been collected from the Ross Sea for a century and the fauna is reasonably documented (Eastman and Hubold, 1999; Vacchi et al., 2000). There are, however, gaps in our knowledge of the composition and distribution of the fauna to the extent that these gaps may obscure possible incidences of temporal change.

Bottom trawling conducted during two recent cruises on the R/V *Nathaniel B. Palmer* (Eastman and Hubold, 1999) provides a preview of conditions and material a fish-sampling program might encounter during the Victoria Land Project. We trawled at depths of 100-1,200 m in the southern and western Ross Sea. We experienced heavy net damage from erratic boulders, thus only 10 of 20 trawls were completely successful. Trawling time of about 15 hours yielded 979 specimens including 46 species (35 notothenioids and 11 non-notothenioids) and 8 families. The collection represents 57% (46/81) of the known Ross Sea fish fauna (Table 1). Since the collection included four new species, 8.7% of the fauna was new to science. We also obtained a new color morph of a known species and eight rare species. In addition, the collection established four new locality records, three second occurrences, three most southerly records and eleven new depth records for fish in the Ross Sea. Over 66% of the total catch by number was taken at depths of less than 400 m and three of the four new species were captured at depths of < 300 m. Notothenioids were dominant by number, consisting of 91.5% of the individuals captured. The most abundant species were *Trematomus scotti* (29.7%), *Bathydraco marri* (10.4%), *Trematomus eulepidotus* (8.7%) and *Dolloidraco longedorsalis* (6.1%). This collection, in conjunction with previous records, indicates that the fish fauna of the Ross Sea south of the 1,000-m isobath includes at least 81 species – 53 notothenioids and 28 non-notothenioids from 14 families (Table 1). This collection also verifies that, even in relatively shallow water, we do not have a complete inventory of the Ross Sea fauna. Thus in addition to its primary focus of identifying latitudinal gradients, the fish collecting program of the Victoria Land Project will likely encounter new species and be establishing new locality and depth records.

Suggestions for Sampling Sites (South → North) 1. Erebus Basin (77°19'S, 165°41'E, 900 m deep) ≈20 km west of Cape Bird. This site could be used to establish baseline species composition for a high latitude deep-water locality. 2. Sponge beds in the shoals (100-250 m deep) east of Beaufort Island (≈77°S, 167°E). Sponge beds are the High Antarctic equivalent of coral reefs – sites of topographic and trophic complexity and therefore relatively high fish diversity. This site could be used to establish baseline species composition for a high latitude shallow-water locality. 3. Top of the Crary Bank or Mawson Bank (300 m deep). These banks run from ≈76° to ≈73°S in N-NE direction about 75 km off the Victoria Land coast. They are separated from the surrounding shelf by basins at least 500 m deep. Bank tops are composed of current-winnowed sediments containing abundant calcareous shell debris and are sites of relatively high fish diversity. 4. Drygalski Trough (≈75°S, 165°E), a 1,200 m-deep innershelf depression north of Terra Nova Bay. Outlet glaciers erode these trenches, thus some of the deepest areas of the high Antarctic shelf are adjacent to the coast. The Drygalski Trough is the deepest and largest innershelf depression in the Ross Sea. Although poorly sampled, these cold stable habitats may have higher proportion of bathydraconids than the surrounding shelf and they are known to contain a new snailfish that may be endemic (Chernova and Eastman, 2001). 5. Waters off Cape Adare (≈72°S) as a site of faunal transition. Here the endemic shelf fauna is supplemented by a mesopelagic oceanic component. Some of these species are found farther south, but it is not known whether these are regular or incidental occurrences. It is possible that they become entrained in and transported south by mesoscale eddies or other water masses containing slightly warmer water. 6. Iselin Seamount (≈71°S, 178°W, 100 m deep) as a site of faunal transition and a dispersal point into the Ross Sea. The Iselin Seamount is north of the shelf break and may be the most southerly seamount. Seamounts are sites of high fish diversity and endemism elsewhere in the South Pacific. In order to be able to recognize range extensions and proportions of species and families that shift with latitude or under changing environmental conditions, the fauna at the periphery of the Ross Sea should be sampled. It is possible that Low Antarctic species are introduced into the Ross Sea via the Iselin Seamount or similar habitats. The nearby Balleny Islands, for example, have nototheniids not found in the Ross Sea.

Possible Sentinel Species With temporal change, it is possible that some Lesser Antarctic species could disperse into or farther south in the Ross Sea. The nototheniid *Notothenia coriiceps* is an example. It has a circum-Antarctic distribution and antifreeze but has not been found in the highest latitudes. Its postlarvae are easily dispersed as they have a long pelagic stage. The first specimen from the Ross Sea was recently collected at Terra Nova Bay (75°S) (Vacchi et al., 2000); it has never been taken in McMurdo Sound (77°30'S). Other species that could be monitored are the nototheniids *Lepidonotothen larseni* and *L. squamifrons*. These species have never been found in the Ross Sea but live around the Balleny Islands.

Final Remark

It is likely that local conditions (patchiness) will be more important than latitude in determining the fish species component of the benthic marine ecosystem along the Victoria Land coast. It is known that the development of an organic matrix, such as coral reefs or macrophyte beds, contributes significantly to an increase in diversity within fish communities (Emery, 1978). This matrix operates by increasing spatial heterogeneity, biological interactions and productivity. Until proven otherwise, there is no reason to assume that benthic fish diversity in the Ross Sea will be determined by different factors. Employing this line of reasoning, sponge beds (the polar equivalent of coral reefs) and shallow bank tops with macrophytes are predicted to be and documented (to a limited extent – Eastman and Hubold, 1999) sites of high fish diversity in the Ross Sea.

Table 1. The 81 species of the Ross Sea fish fauna including both benthic shelf species and mesopelagic oceanic species. Northern limit of the Ross Sea taken as Cape Adare (≈72°S) on the coast and the 1,000 m isobath offshore. Based on Eastman and Hubold (1999) with updates and corrections. Nomenclature for notothenioids follows Eastman and Eakin (2000). Askerisk (*) indicates the 46 species captured by benthic trawling during cruises NBP 96-6 & 97-9.

Family and Species

- Rajidae
  - Bathyraja eatonii*
  - Bathyraja maccaini*
  - Bathyraja sp.*
  - Raja georgiana
- Bathylagidae
  - Bathylagus antarcticus
- Paralepididae
  - Notolepis coatsi
- Myctophidae
  - Electrona antarctica
  - Gymnoscopelus
    - braueri
    - nicholsi
  - Krefftichthys anderssoni
  - Lampanyctus achirus
  - Protomyctophum bolini
- Muraenolepididae
  - Muraenolepis microps*
- Macrouridae
  - Macrourus whitsoni
- Melanocetidae
  - Melanocetus rossi
- Oneirodidae
  - Oneirodes notius
- Liparidae
  - Careproctus polarsterni
  - Edentoliparis terraenovae
  - Paraliparis
    - andriashevi
    - antarcticus*
    - devriesi
    - fuscolingua
    - macrocephalus **n. sp.***
    - rossi **n. sp.***
- Zoarcidae
  - Lycodichthys dearborni*
  - Ophthalmolycus
    - amberensis*
    - bothriocephalus*
  - Pachycara brachycephalum*
- Nototheniidae
  - Aethotaxis mitopteryx
  - Dissostichus mawsoni
  - Gvozdarus svetovidovi
  - Notothenia coriiceps
  - Pagothenia
    - borchgrevinki
    - brachysoma
  - Paranotothenia dewitti
  - Pleuragramma antarcticum*

Family and Species (continued)

  - Trematomus
    - bernacchii*
    - eulepidotus*
    - hansoni
    - lepidorhinus*
    - loennbergii*
    - newnesi*
    - nicolai
    - pennellii*
    - scotti*
    - tokarevi
- Artedidraconidae
  - Artedidraco
    - glareobarbatus **n. sp.***
    - loennbergi*
    - orianae*
    - shackletoni*
    - skottsbergi*
  - Dolloidraco longedorsalis*
  - Histiodraco velifer*
  - Pogonophryne
    - albipinna
    - barsukovi
    - cerebropogon **n. sp.***
    - lanceobarbata*
    - macropogon
    - marmorata*
    - mentella
    - permitini
    - scotti*
- Bathydraconidae
  - Acanthodraco dewitti
  - Akarotaxis nudiceps*
  - Bathydraco
    - macrolepis*
    - marri*
    - scotiae
  - Cygnodraco mawsoni*
  - Gerlachea australis*
  - Gymnodraco acuticeps*
  - Prionodraco evansii*
  - Racovitzia glacialis*
  - Vomeridens infuscipinnis*

Family and Species (continued)
Channichthyidae
Chaenodraco wilsoni
Chionodraco
*hamatus**
*myersi**
*Cryodraco antarcticus**
*Dacodraco hunteri**
*Neopagetopsis ionah**
Pagetopsis
*macropterus**
*maculatus**

PENGUIN PALEOHISTORY AND CLIMATE CHANGE IN THE ROSS SEA REGION

Steven D. Emslie

Hundreds of thousands of Adelie penguins (*Pygoscelis adeliae*) occur along the Victoria Land Coast and in the Ross Sea region, Antarctica. The chronological extent of their occupation of this region is unknown, but research by Baroni and Orombelli (1991, 1994) has provided important data on penguin paleohistory (13,000 B. P. to the present) in relation to sea ice conditions, glacial retreat, and climate. In addition, previous research at abandoned and active penguin colonies in the Antarctic Peninsula has indicated that Adelie penguin diet varies with climate as well as with latitude in that region (Emslie et al. 1998; unpubl. data). The cause for these variations is unknown and in need of additional investigation. Preliminary data gathered by the author in the Ross Sea region in 2001 currently is under analysis and may indicate similar trends as in the peninsula. The Victoria Land Program offers a unique opportunity to further develop international collaboration in addressing these and other questions related to penguin paleohistory and climate change in this region.

Adelie penguins need open water near their breeding colonies to successfully raise their chicks. Many abandoned colonies ranging from hundreds to thousands of years old are located along coastal margins that currently no longer have persistent open water each season that would ensure reproductive success. Long-term shifts in temperature and sea ice conditions obviously have influenced population movements and colony locations of this species. Thus, additional investigations of abandoned penguin colonies potentially can provide proxy data for sea ice conditions, and climate change, in the past. Moreover, organic remains preserved in these sites (penguin tissue, eggshell, and dietary remains) also can yield considerable information on how penguins respond to climate change with shifts in diet and foraging locations.

Research on abandoned colonies on Ross Island and along the Scott Coast was initiated by the author in January/February 2001 (see http://www.uncwil.edu/tc/antarctica2/antarctica.html). Ten abandoned and three active Adelie penguin colonies were located and sampled for organic remains. Radiocarbon dates on penguin bones and tissue from these excavations are pending. Many of these sites originally were identified and dated by Baroni and Orombelli (1994); several others were sampled for the first time and include one at Cape Barne (77° 34' 33" S, 166° 14' 32" E) that is the most southern Adelie penguin colony, past or present, known in Antarctica. Areas of ice-free terrain farther south from Cape Barne, including islands and capes south of the Ross Sea Ice Shelf, were surveyed but no additional sites were located.

The radiocarbon chronology that will result from these analyzes will supplement that published by Baroni and Orombelli (1994). These authors identified a period of penguin population expansion, the penguin 'optimum,' at 3000-4000 B. P. They hypothesize that a warming event at that time allowed penguins to extend their breeding colonies farther to the south in the Ross Sea than their present distribution. Data gathered by the author at Cape Barne and other localities may lend support to this 'optimum' warming event. In addition, many of the abandoned colonies are located on raised beaches along the Victoria Land coast. Radiocarbon dates on penguin remains from these sites will provide a minimum age for exposure of these beaches above sea level and will aid in developing sea level curves for this region. This research can be completed in collaboration with geologists currently investigating sea level change along the Victoria Land coast (e.g., Berkman et al. 1998; Hall and Denton 1999).

Several other collaborative studies can be completed with organic remains from abandoned colonies that are pertinent to the Victoria Land Program. These studies include investigations of ancient DNA, isotopic analyses of eggshell fragments, and comparisons of past and present diet of penguins with latitude. Studies of ancient penguin DNA were initiated by Dr. David Lambert (D.M.Lambert@massey.ac.nz) and Peter Richie in the Ross Sea region in 1998 (http://www.massey.ac.nz/~pritchie/methods.html). A collaborative project currently is being developed with Dr. Lambert to identify the mitochondrial lineages that can be traced from living to subfossil Adelie penguins. This research will help track changes in the geographic distribution of major populations that may be correlated with episodes of climate change. Dr. David Ainley (Dainley1@cs.com) currently is investigating the foraging ecology and diet of Adelie penguins on Ross Island. Data collected from abandoned sites, including paleodiet information, can be compared with his results in another collaborative effort. In addition, isotopic analyses (Carbon, Nitrogen, and Oxygen) of penguin eggshell from active and abandoned colonies may provide signatures that are indicative of specific water masses and foraging areas currently used by penguins. Similar signatures from eggshell fragments in abandoned colonies could help trace shifts in diet and foraging locations that can be correlated with the paleoclimatic record.

Numerous other abandoned and active penguin colonies occur from Cape Adare south to the Drygalski Ice Tongue in the Victoria Land region (Baroni and Orombelli 1991, 1994). Additional investigations at these sites are warranted. Staging areas for this research could be established at Terra Nova Bay and Cape Hallett as a part of the Victoria Land Program. This research would provide a latitudinal gradient of penguin occupation (past and present), a database of radiocarbon dates that can be used to evaluate changes in sea ice conditions through time, and organic remains dating from the late Pleistocene through Holocene that can be analyzed with collaborative investigations on living penguins, ancient DNA, and isotope geochemistry.

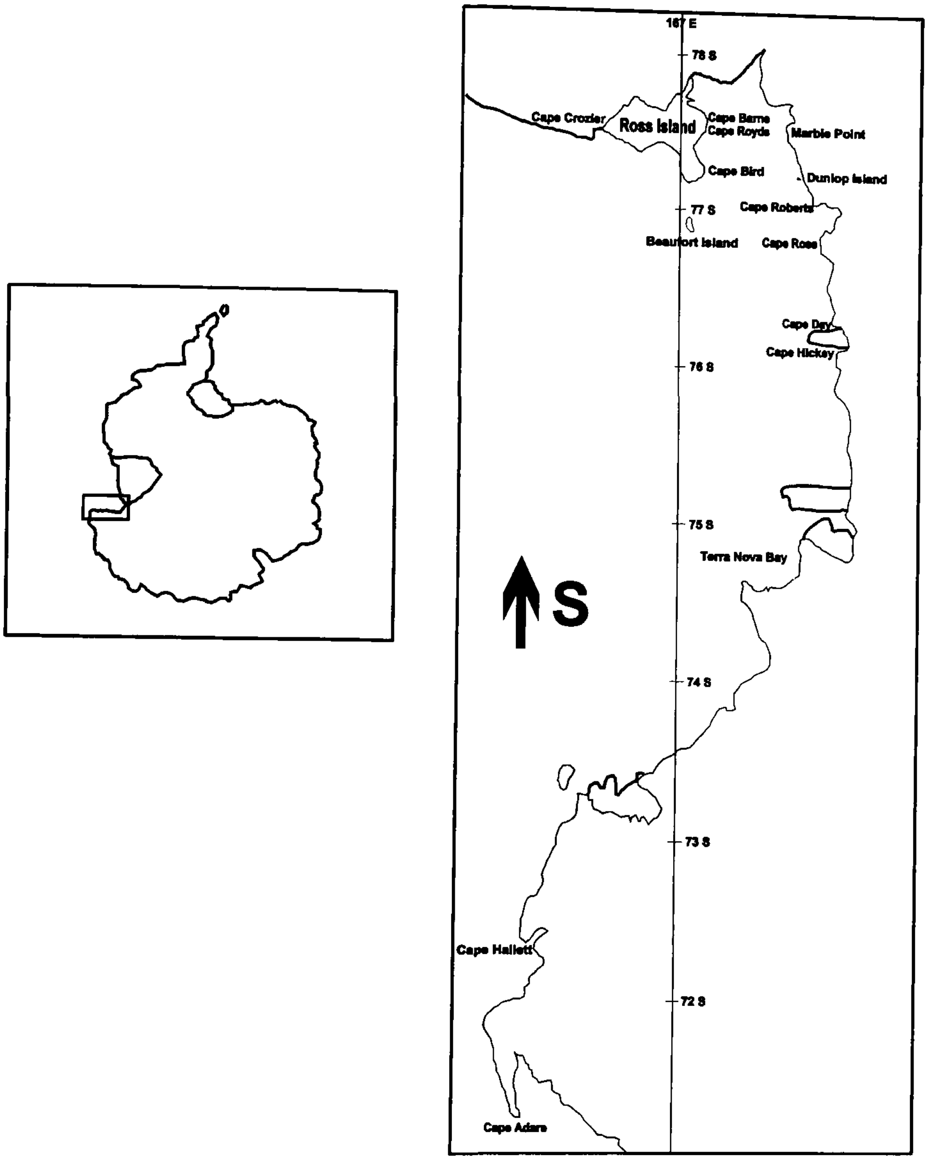


Figure 1. Map of the Victoria Land Coast and Ross Sea region showing the location of abandoned and active Adelie penguin colonies discussed in the text.

ECOLOGY OF SEA ICE BIOTA: CHARACTERISTICS AND DYNAMICS IN ACROSS-SHELF ENVIRONMENTAL GRADIENTS

Christian H. Fritsen

It is known with reasonable confidence that the structure and dynamics of sea ice biotic communities differs greatly between land-fast sea ice attached to the continent and the pack ice that drifts in response to ocean dynamics. Furthermore, there is increasing evidence (both theoretical and observational) suggesting that differences exist between biotic communities within pack ice that are influenced by the continental shelf and those that lie beyond the shelf break (http://www.dri.edu/DEES/Faculty/Fritsen.html, see Victoria Land Workshop, Figures A and B). However, the distribution and characteristics of these habitats and communities along this environmental gradient have rarely been documented. Hence, paradigms regarding the contribution of the Antarctic sea ice ecosystem to the seasonal production and export cycles of materials of local ecological and global importance (e.g. Carbon, Nitrogen, Iron, DMS) are not well constrained.

Cruises along the continental shelf and the coastal margins of Antarctica provide an ideal opportunity to assess the distribution; abundance and activity of sea ice biota among the aforementioned functionally important sea ice regimes. During the proposed activities along Victoria Land's coast, experiments and sampling should be designed to compare the environmental characteristics (e.g. temperature, salinity, light, nutrients) of sea ice habitats, as well as the microscale (meters to micrometers) distribution and physiology of the biota within these sea habitats along the continental margin that are linked to the time-varying dynamics of Circumpolar Deep Water. Such a comparison will allow more rigorous testing of conceptual (Garrison et al. 1986, Fritsen and Sullivan 1999) and quantitative models (Fritsen et al. 1998) on the differences between the biota and their dynamics in these distinct mesoscale ice regimes and how these respond to global changes at varying time scales.

SCALING IN SPACE AND TIME: PLANT CARBON CYCLING IN AN ARCTIC RIVER BASIN

John E. Hobbie

Abstract

Under the Arctic Systems Science and Long Term Ecological Research programs at NSF, data were collected on the Kuparuk River basin, Alaska, which covers ~9,000 km^2 including Prudhoe Bay. The projects contributing data to this modeling exercise were led by Oechel (CO_2 fluxes), Chapin (CO_2 and energy fluxes), Hinzman and Kane (climate), Hinkel and Nelson (thaw depth and soil moisture), Walker (vegetation mapping), and Rastetter, Williams, and Hobbie (modeling). Data from the ARCTIC LTER Project at Toolik Lake, within the Kuparuk basin, were provided by Shaver.

The Soil Plant Atmosphere (SPA) model was developed for forests. It is basically a photosynthesis model that operates at 10 levels in the forest canopy and includes radiation and moisture transfer as well as water uptake from soils. It has climate as a driver and operates at a 30 minute time step. A crucial controlling factor is the amount of nitrogen in the leaves – that is, the enzymes that control the rate of photosynthesis. The nitrogen content of leaves in the Arctic is linked to the NDVI which is sensed from a satellite. The model has been parameterized for the Arctic and tested against eddy flux data for carbon cycling at a number of sites in the Kuparuk River basin. Using extrapolated climate data and NDVI from a satellite, the model was run for an entire summer for each of the 9,000 km^2 units in the Kuparuk River basin to produce a map of the gross annual primary production for the entire basin.

This model can not be used for a prediction into the future because it requires data from a satellite which are, of course, not available for the future. Instead a different model is used. This is the called the MBL General Ecosystem Model.

In GEM, plants are represented as leaves, stems, and roots. Carbon and nitrogen is exchanged between vegetation and soils. The model runs on an annual time step, driven by annual temperature, irradiance, and soil moisture. The model is trained using data describing vegetation and soils in arctic tussock tundra at Toolik Lake. Data include results from tundra grown for years under altered environments of raised temperature, added fertilizer, and increased CO_2. A single version of the model can predict carbon cycling under all of these altered environments. When the model is driven with a scenario of climate warming in the future, carbon accumulates in the ecosystem. However, the quantity of carbon and the location (soil vs. vegetation) of the storage will vary with relatively small changes in the soil moisture. A recent version of GEM can also be run on a spatial grid within the Kuparuk basin.

The main problem right now for running these models is lack of detailed climate data for the Arctic.

GRADIENTS OF CLIMATE IN CONTROLLING SHALLOW-WATER MICROBIAL COMMUNITIES ACROSS VICTORIA LAND

Ian Hawes, Clive Howard-Williams, Anne-Maree Schwarz and Doug Mountford

Microbial mats dominated by mat forming cyanobacteria are characteristic of shallow waters across the length of Victoria Land. These water bodies include glacial melt streams (Howard-Williams et al 1986, Vincent 1988, McKnight et al 1998), ice-shelf ponds (Howard-Williams et al 1989, Hawes et al 1993), inland coastal ponds (Schmidt et al 1991, Broady 1993, Vincent 1988) and ponds in coastal tidally influenced "lagoons" (Hawes et al 1998, Downes et al 2000, S. Bowser Pers Comm) and high altitude ponds (Broady and Weinstein 1998) and the moats of the permanently ice covered lakes (Wharton et al 1983)

Pond and stream mat communities have been studied in a New Zealand Science Foundation funded series of research contracts over the last two decades on the vicinity of McMurdo Sound (Dry Valleys and McMurdo Ice Shelf at Bratina Island). In future work relating to a Latitudinal Gradient Project (cf. Peterson and Howard-Williams 2001), these communities in the central area of Victoria Land will be used as reference sites for comparison with communities north and south.

We anticipate that from North to South (72-86 ° S) the following environmental gradients will influence community biodiversity, biocomplexity, biogeochemical and metabolic pathways: Solar radiation will decrease, mean annual temperature, maximum summer temperature, and the length of the thaw period will decrease. The number of freeze-thaw cycles will increase and then decrease. Length of the dark period will increase. The availability of free water will decrease and the degree of salinisation of surface waters will increase.

Furthermore it is expected that there will be a step in these gradients at the transition from the coastal zone influenced by the Ross Sea and sea-ice to the "coastal" zone influenced by the Ross Ice Shelf (approximately 78 ° S).

As a consequence, the following North to South ecosystem responses are hypothesised: Species diversity will decrease, maximum biomass will decrease, the ratio of cyanobacteria to other taxa on the mat community will increase, rates of nitrogen fixation will decrease, nitrogen storage will decrease, growth rates will decrease, particularly on an annual time scale) and biomass turnover times will decrease, the presence of anaerobic pathways will decrease as annual and daily rates of respiratory metabolic pathways decrease.

Methods

We will characterise the extent of temperature (air, water sediment), solar radiation, and conductivity in ponds along the gradient by installing and maintaining remote data logging equipment.

Species diversity will be examined and the physical and chemical characteristics of the microbial mats will be quantified along a latitudinal gradient from Cape Adare to the La Gorce Mountains. Characteristics such as mat thickness, pigment composition, mat complexity and structure, cohesiveness, strata, and microstructure will be determined.

We will determine composition, activity and major metabolic pathways of carbon and nitrogen of microbial mats along the gradient.

Production to respiration ratios of the dominant autotrophs along the gradient will be measured, and methods of maximising available light (migration, pigment to biomass rations and photosynthetic parameters (Light limitation parameter (ά), P-max) will be examined, and measured. The role of heterotrophs and micro-grazers will be examined.

The extent of anaerobic activity will be tested from measurements of methanogenesis:sulphate reduction, respiratory index for sulphate metabolism:terminal carbon/electron partitioning, and carbon:nitrogen turnover ratios.

Modelling

An important component of this study will be the production of a growth model for microbial mats across the gradient (see eg Moorhead et al 1998). This will begin with the production of a conceptual model of the likely effects of latitudinally induced climate change on shallow water on aquatic communities, followed by a numerical (hopefully predictive) model which allows for growth, and mat type across the range of conditions experienced between latitudes 72 to 86 degrees south.

SEA ICE CHARACTERISTICS AND PROCESSES IN THE SOUTHWESTERN ROSS SEA

Martin O. Jeffries, Kim Morris and Nickolai Kozlenko

Introduction

For the purpose of describing sea ice characteristics and processes in the southwestern Ross Sea in the context of the Victoria Land Coastal Biome the ice cover is divided into three basic categories: landfast ice, pack ice and polynyas. Each category is clearly visible in the NOAA AVHRR image (Figure 1). The emphasis of this paper is on the geophysics of the ice cover, with some description of ice and ocean ecology where appropriate.

Landfast ice is anchored to the shore and/or the sea bed. It may move up and down with the tide, and with ocean waves and swell, but horizontal movement (advection) is minimal. Here the focus is on the landfast ice in McMurdo Sound (Figure 1), which has received by far the greatest attention over the years from geophysicists and biologists.

Pack ice is not anchored. It too is free to move with the tide, and with ocean waves and swell, but more importantly it advects, often at great speed, under the influence of the wind and ocean currents. Here the focus is on the pack ice between the ice edge and the front of the Ross Ice Shelf along the 180° meridian.

Polynyas are areas of ocean that remain either partially or totally free of ice at times and under meteorological conditions when the water surface would be expected to be totally covered with ice. There are a number of polynyas in the southwestern Ross Sea. Here the focus is on the Terra Nova Bay polynya and the Ross Sea polyna (Figure 1).

Landfast Sea Ice

The annual break-up of the landfast ice and a brief late summer/early autumn open water period in McMurdo Sound is associated with the annual resupply of McMurdo Station that begins in early January with the arrival of a U.S. Coast Guard icebreaker to cut a channel through the landfast ice (Figure 2a). Much of the ice breaks out each year, apart from some sheltered locations such as New Harbour, where perennial or multiyear ice persists (Figure 2a). Otherwise, McMurdo Sound is covered with seasonal or first-year ice and McMurdo Station is icebound for much of the year (Figures 1 and 2a).

From the onset of ice growth in autumn until roughly July, the landfast ice thickens by congelation ice growth (Figure 3a), i.e., columnar, vertically oriented crystals that grow down into the water as heat is conducted up through the ice and overlying snow to the atmosphere. The congelation ice commonly becomes strongly anisotropic as its c-axes become aligned with the prevailing ocean currents [Gow et al., 1982, 1998; Jeffries et al., 1993; Jones and Hill, 2001]. The congelation ice therefore contains a record of the ocean circulation below the landfast ice [Gow et al., 1981, 1998].

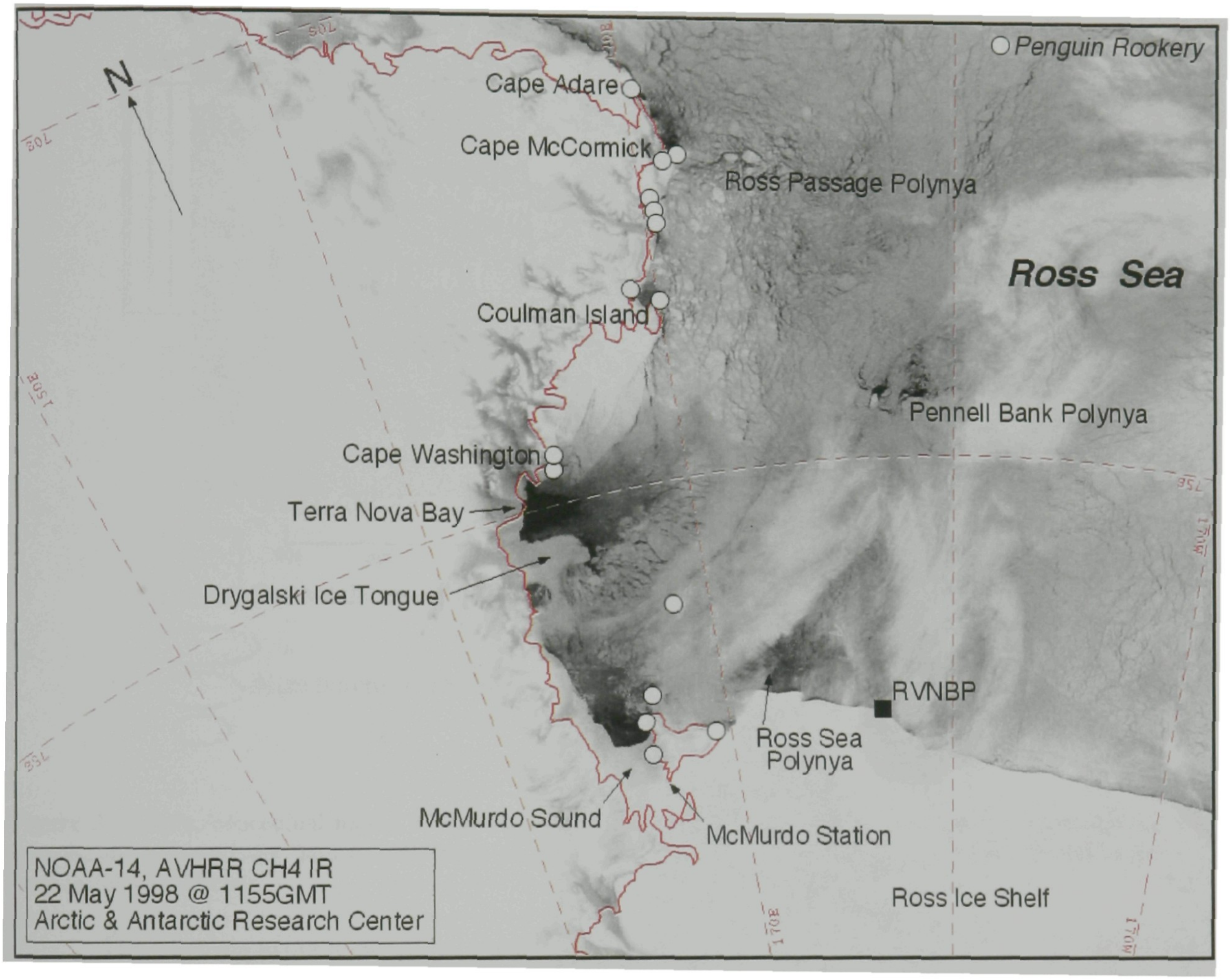


Figure 1. NOAA AVHRR image of the southwestern Ross Sea showing landfast sea ice, pack ice and polynyas on 22 May 1998. Locations mentioned in the text are marked. The penguin (Adélie and Emperor) rookeries are from the Ross Sea Regions map, 3rd Edition, 1987 (Department of Survey and Land Information, New Zealand). The image was supplied by the Arctic and Antarctic Research Center, Scripps Institution of Oceanography, San Diego, CA.

In roughly July the oceanography of McMurdo Sound and the style of landfast ice thickening change as platelet ice crystals appear at the base of the landfast ice sheet (Figure 3b). The platelets are dendrite-like crystals that are 1-3 mm thick and up to 100 mm across [Arrigo et al., 1993a; Gow et al., 1998]. There is some debate as to whether the platelets form deep in the water column then float up and accumulate at the base of the landfast ice, or whether they nucleate in situ at the base of the ice. On the other hand, it is generally agreed that the platelets owe their origin to the adiabatic decompression and thus supercooling of low density water that flows into McMurdo Sound from below the Ross/McMurdo Ice Shelf [Lewis and Perkin, 1985; Crocker and Wadhams, 1989]. What triggers the outflow of low density water and thus the onset of platelet crystal growth remains unclear.

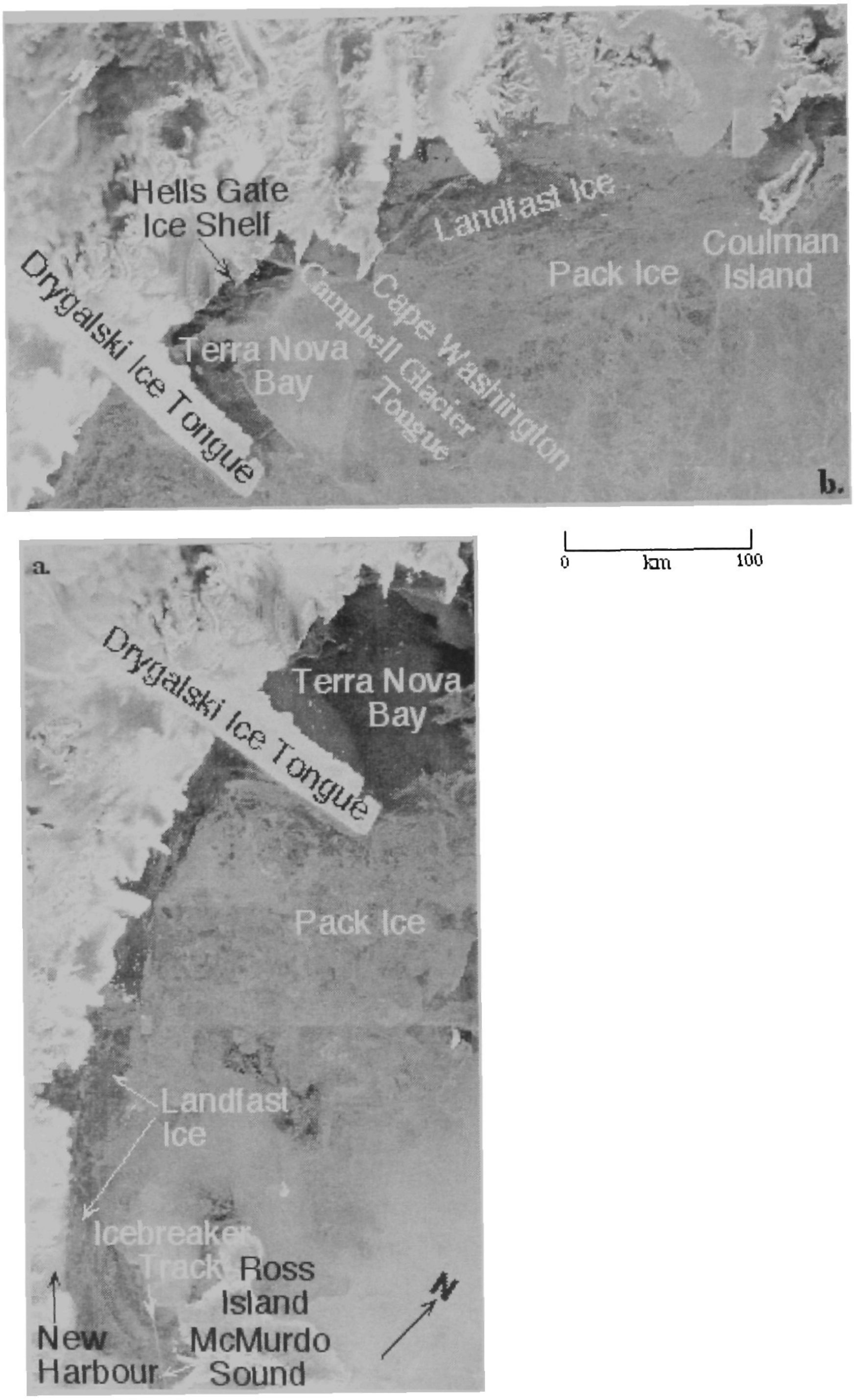


Figure 2. Sub-scenes of RADARSAT ScanSAR Wide B SAR (synthetic aperture radar) images. (a) McMurdo Sound to Drygalski Ice Tongue and Terra Nova Bay, 7 January 2000. (b) Drygalski Ice Tongue and Terra Nova Bay to Coulman Island, 5 November 1997. Each scene has the same scale. The original SAR images (©CSA) were supplied by the Alaska SAR Facility, University of Alaska Fairbanks.

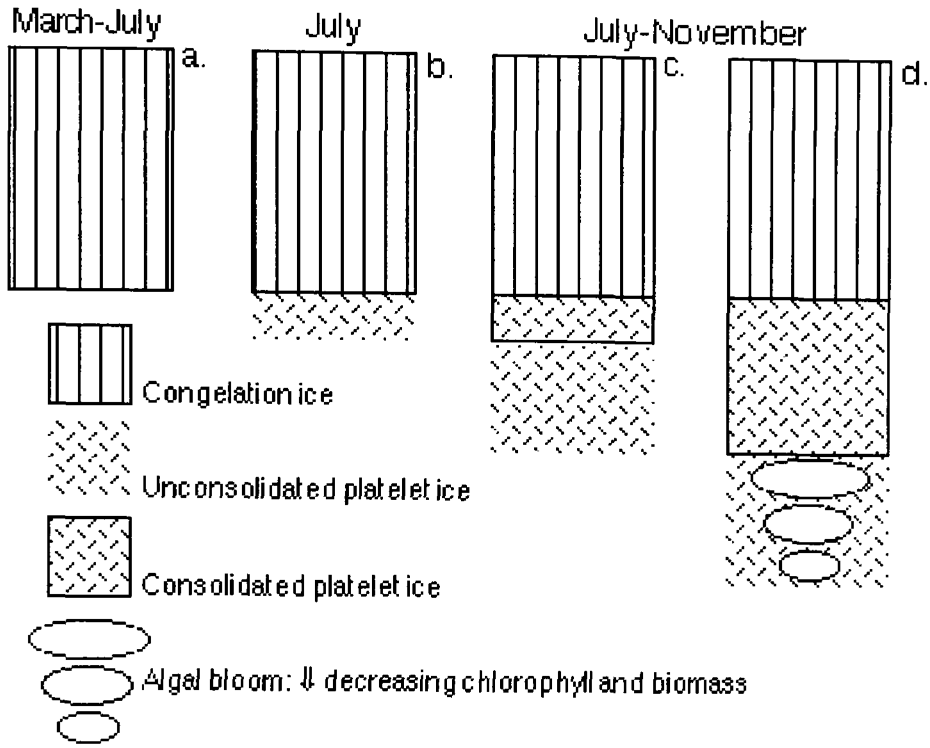


Figure 3. Simple, conceptual model of the thickening of the McMurdo landfast ice through congelation ice growth, and accumulation and consolidation of platelet ice crystals, with a spring microalgal bloom in the unconsolidated platelets.

The platelets accumulate in an unconsolidated, highly porous mass (20% ice, 80% water [Bunt, 1964]) that can extend up to 5 m down into the water column below the solid landfast ice [Arrigo et al., 1993a]. Meanwhile, congelation ice growth continues at the interface between the solid ice and the unconsolidated platelets, and platelet ice crystals are entrained into the landfast ice sheet as water freezes around them (Figure 3c). Consequently, by the time the landfast ice reaches its maximum thickness of 2 m or more in December, it is composed of a layer of "pure" congelation ice overlying a layer of consolidated platelet ice (Figure 3d). At this time, a layer of unconsolidated platelets might remain, but with the onset of summer they begin to melt and disappear, exposing the base of the landfast ice, which also begins to melt.

Platelet ice has been reported elsewhere in the water column and sea ice of Antarctica [e.g., Dieckmann et al., 1986; Eicken and Lange, 1989; Lange et al., 1989; Penrose et al., 1994], but McMurdo Sound is one of the more accessible places to study a phenomenon that represents the complex interactions that occur between the ocean, ice shelf and sea ice. In addition to its glaciological and oceanographic significance, the accumulation of platelet ice crystals at the base of the McMurdo landfast ice also has important microbiological consequences.

Significant chlorophyll production and biomass accumulation have been observed as a microalgal bloom occurs in the unconsolidated platelets, with the highest concentrations in the topmost layer immediately below the solid ice (Figure 3d) [Arrigo et al., 1992, 1993b, 1995]. Numerical simulations indicate that up to 76% of the primary production rate in the McMurdo landfast ice ecosystem occurs in the unconsolidated platelet ice layer [Arrigo et al., 1993a]. The combination of a stable substrate, large surface area, and potential for seawater exchange within the unconsolidated platelet ice layer may be primarily responsible for the high productivity [Grossi et al., 1987; Arrigo et al., 1993b]. Landfast ice occurs at numerous other locations between McMurdo Sound and Cape Adare, although the spatial and temporal variability of ice growth and decay are not well documented. There appears to be a continuous fringe of landfast ice between McMurdo Sound and the Drygalski Ice Tongue (Figures 1 and 2a). The latter impedes the northward motion of pack ice along the coast and a zone of "pseudo-fast ice" accumulates on its south side (Figure 2a). Jeffries and Weeks [1992] observed platelet ice in sea cores from this area and suggested that they were evidence of low density water outflow from beneath the melting base of Drygalski Ice Tongue.

The blocking effect of the Drygalski Ice Tongue is a key factor in the dynamics of the Terra Nova Bay polynya [Bromwich and Kurtz, 1984; Kurtz and Bromwich, 1983, 1985], which is discussed in more detail in the section on polynyas. Nevertheless, landfast sea ice occurs in Terra Nova Bay, e.g., at the front of Hells Gate Ice Shelf and on each side of Campbell Glacier Tongue (Figure 2b). Consolidated plaletet ice has been observed in this landfast ice [Tison et al., 1998; Jeffries, unpublished data].

Between Cape Washington and Coulman Island there are a number of glacier tongues, and they are all enclosed by landfast ice (Figure 2b). This might be multiyear ice and thus quite thick with a deep snow cover. There might also be platelets accumulating and consolidating at the base of the ice, particularly in the immediate proximity of the glacier tongues. Even if unconsolidated platelets exist at the base of the ice, the potentially large total thickness of snow and ice would affect light availability and thus the microbial ecosystem and how it compares to the first-year ice ecosystem in McMurdo Sound.

Pack Ice

Sea ice extent in the southwestern Ross Sea oscillates at a period of 4-5 years, with summer minima roughly in phase with winter maxima [Jacobs and Giulivi, 1998]. Higher winter and lower summer ice extents are accompanied by stronger northward winds and higher local air temperatures, and are followed by higher shelf water salinities [Jacobs and Giulivi, 1998]. A four-decade (1955-1995) trend toward higher air temperature and lower shelf water salinity could imply a thinning of the sea ice cover during that time [Jacobs and Giulivi, 1998].

Only recently have sea ice thickness data become available for the southwestern Ross Sea. Data obtained during cruises aboard the R. V. Nathaniel B. Palmer (RVNBP) in autumn 1995 and 1998 offer some insight into the spatial and inter-annual variability of first-year ice thickness along 180° longitude between the northern ice edge and the front of the Ross Ice Shelf (Figure 4). Apart from a region of thinner ice between 71-72°S in 1995, due to reduced ice concentration in the vicinity of the continental shelf break, the 1995 and 1998 records have similar features: (1) relatively thin ice in the marginal ice zone adjacent to the open ocean; (2) ice thickness increases with increasing distance from the ice edge, with a broad maximum between 71-76°S; and (3) ice thickness decreases in the southernmost region of the pack ice near the continent [Morris et al., unpublished MS].

The ice thickness distribution (Figure 4) is, in effect, an age distribution. The thinner ice near the continent is relatively young, having formed in the coastal zone where offshore winds push the pack ice away from shore creating open water that freezes. Offshore winds and ice conditions at the front of the Ross Ice Shelf are discussed in more detail in the next section. The thinner ice in the marginal ice zone is relatively young ice that forms as the ice cover expands northward and increases in area by in situ growth. Between the two young ice zones is a zone of older first-year ice that is being advected northward.

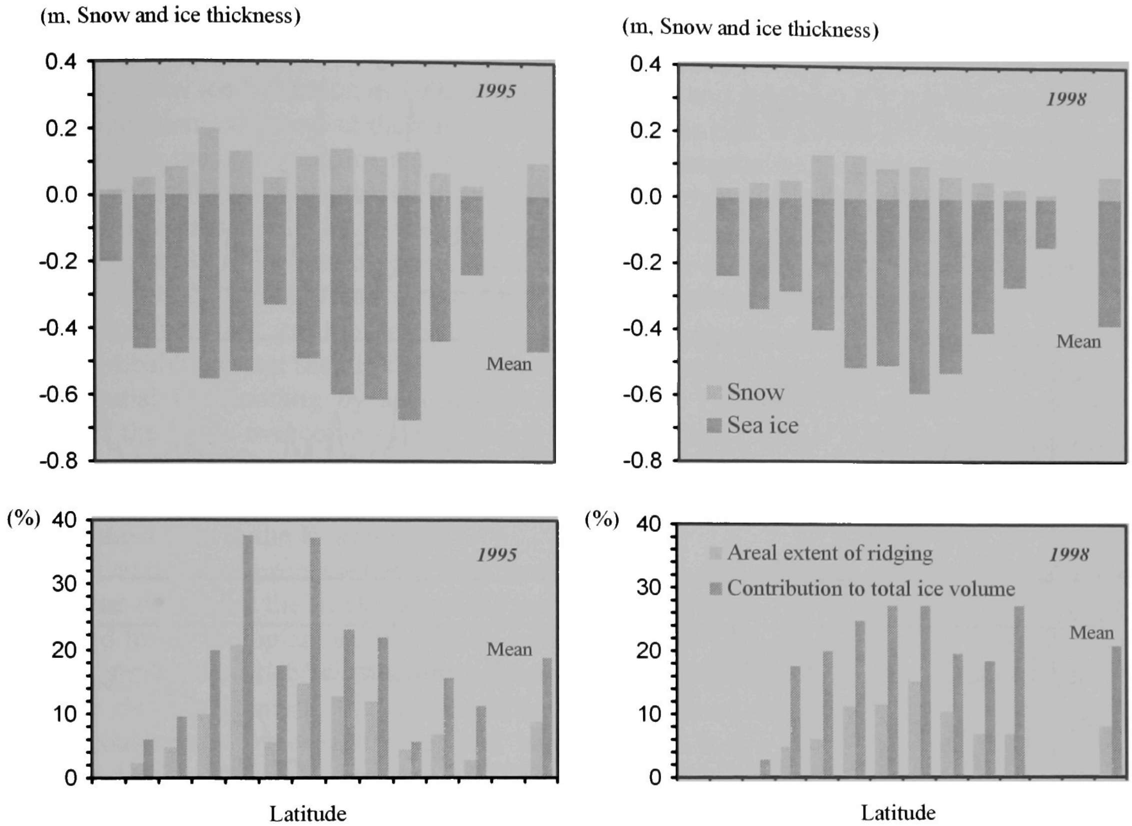


Figure 4. Thickness of unridged sea ice and snow depth (top) and areal extent of ridges and their contribution to the total ice mass (bottom) along longitude 180° in the western Ross Sea in May 1995 and May 1998 [source: *Morris et al.*, unpublished MS].

There is rapid northward ice advection in the southwestern Ross Sea, as illustrated by Argos buoys deployed on the ice in 1986-88 [Moritz, 1988] and by GPS-equipped buoys deployed in 1998 [Jeffries and Kozlenko, in press; Kozlenko and Jeffries, unpublished MS]. The GPS buoys drifted north-northwestward at a mean speed of 14.2±7.7 km d^{-1} on the continental shelf and shelf slope, and 13.5±11.0 km d^{-1} on the deep ocean (Figure 5) [Kozlenko and Jeffries, unpublished MS]. As the ice cover moved northward, it was also deforming, with a net divergence of -1.4% d^{-1} (i.e., closing) on the continental shelf and shelf slope, and 0.4% d^{-1} (i.e., opening) on the deep ocean (Figure 5) [Kozlenko and Jeffries, unpublished MS]. The net convergence on the continental shelf and shelf slope would account to some degree for the higher ice concentration (94.8±4.2%) there than on the deep ocean (87.8±3.8%) (Figure 5). One obvious manifestation of ice deformation is the widespread occurrence of ridges that represent the dynamic thickening of initially thin ice by convergent forces. In 1995 and 1998, ridges made up as much as 15-20% of the ice cover and as much as 30-40% of the total ice mass (Figure 4). Overall, the ice cover was thinner and ridges were less widespread in 1998 than in 1995 (Figure 4). This has been attributed to the occurrence of more persistent southerly winds in 1998 that resulted in a more divergent ice cover with greater open water and thin ice, and thus a lower area-averaged ice thickness [Morris et al., unpublished MS].

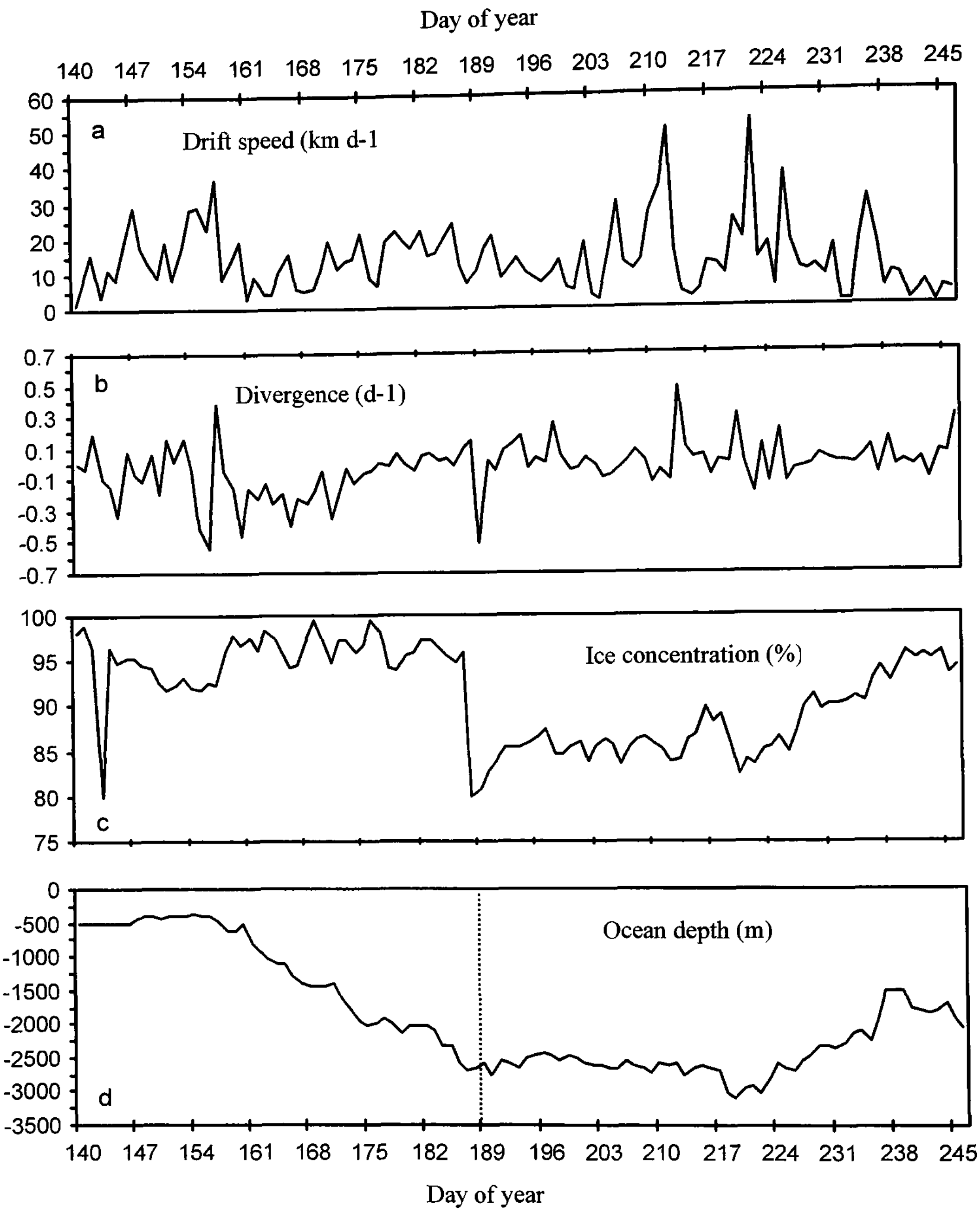


Figure 5. Daily drift speed (a) and divergence (b) of the Ross Sea ice cover derived from four buoys operating on pack ice floes between 20 May (day 141) to 2 September (day 246) 1998 [*Kozlenko and Jeffries*, unpublished MS]. The buoys were deployed in an array straddling 180° longitude between 75-76°S and ceased to operate in the vicinity of the SE Balleny Islands, 67° 45'S, 165°E. The daily ice concentration data (c) are derived from satellite passive microwave data available at the National Snow and Ice Data Center, Boulder, Colorado. The ocean depth (d) along the buoy drift track is based on ETOPO5 5-minute gridded elevation data available at the National Geophysical Data Center, Boulder, Colorado. The vertical dotted line represents the boundary between the inner and outer pack ice.

Before the ice can thicken dynamically, it must first form and thicken thermodynamically, i.e., seawater must freeze. In the Ross Sea, as elsewhere in the Antarctic seas, initial thermodynamic ice growth and areal expansion of the ice cover in early autumn is probably dominated by frazil ice growth and pancake ice formation [Jeffries and Adolphs, 1997; Jeffries et al., 2001]. Further thermodynamic thickening of the ice cover proceeds along geographically distinct lines, with the inner pack ice south of 70-71°S being dominated by congelation ice growth, and the outer pack ice north of 70-71°S being dominated by snow ice formation in 1995 and 1998 [Jeffries and Adolphs, 1997; Jeffries et al., 2001].

Congelation ice grows at the base of the ice cover as heat is conducted away from the ice-water interface through the overlying ice and snow. The rate of congelation ice growth is controlled by the air temperature (which determines the temperature gradient in the snow and ice) and the oceanic heat flux. Since air temperatures are colder in the southern Ross Sea than in the northern Ross Sea, and the oceanic heat flux is probably lower on the continental shelf than on the deep ocean, the conditions in the inner pack ice are probably more favourable for congelation ice growth [Jeffries and Adolphs, 1997].

In the outer pack ice, closer to the moisture source, precipitation and snow accumulation on the sea ice are probably greater than in the inner pack ice [Jeffries and Adolphs, 1997]. Consequently, there is greater potential for flooding by seawater/brine and slush formation at the snow/ice interface as the buoyancy of the ice is overcome by the weight of accumulating snow. When the slush freezes, the ice thickens by snow ice formation. Numerical simulations [Maksym and Jeffries, 2000] and observations [Jeffries and Adolphs, 1997; Jeffries et al., 2001] indicate that flooding and snow ice formation can occur throughout the winter in the Ross Sea.

Just as physical processes affect the landfast sea ice microbial ecosystem, so too do the physical processes that determine the thickness of the pack ice. High chlorophyll concentrations, higher than can be accounted for by biological activity alone, have been reported in consolidated frazil ice [Ackley, 1982; Garrison et al., 1983]. Theoretical and experimental investigations suggest that this is because the biota are initially deposited among the unconsolidated frazil ice crystals, which act as a filter as water is pumped through them by ocean waves and swell [Ackley et al., 1987; Shen and Ackermann, 1990]. Fritsen et al. [1994, 1998] and Arrigo et al. [1998a] have observed and simulated algal blooms associated with nutrient-rich seawater flooding of the snow/ice interface. The ice surface can also be depressed below sea level due to the weight of ice in a ridge, and the resultant surface saline ponds can harbour a diverse microbial ecosystem [Ackley, 1986; Ackley and Sullivan, 1994]. Algal mats have been observed clinging to the submerged ice blocks of pressure ridge keels [Ackley and Sullivan, 1994].

In view of the evidence for widespread frazil ice growth, flooding due to snow load, and pressure ridging in the western Ross Sea pack ice, there is considerable potential for sea ice ecosystem diversity and high productivity. Preliminary results of Ross Sea ice ecosystem studies in autumn 1998 indicate that this is the case [D. L. Garrison, personal communication, June 2001]. On average, for the entire pack ice, the highest Chlorophyll a concentrations occurred in snow ice, followed by frazil ice and congelation ice. On the other hand, chlorophyll concentrations in frazil ice in the outer pack ice were significantly higher than those in frazil ice in the inner pack ice, and since there was a greater amount of frazil ice in the outer pack ice, integrated chlorophyll stocks were higher there too.

Polynyas

The Terra Nova Bay and Ross Sea polynyas (Figure 1) are particularly well known and have been the subject of a number of physical and biological studies, but there are other polynyas in the region. Jacobs and Comiso [1989] identified two polynyas on the continental shelf break: the Ross Passage polynya and the Pennell Bank polynya (Figure 1), which they believe are maintained by divergence above a submarine bank and upwelling of warmer water near the slope front. Figure 1 also shows a significant area of open water/thin ice along the McMurdo landfast sea ice edge, with smaller areas at the northern end of Coulman Island and between Cape McCormick and Cape Adare. The correlation between polynyas and penguin rookeries is difficult to ignore (Figure 1).

According to Bromwich and Kurtz [1984] and Kurtz and Bromwich [1983, 1985] the polynya in Terra Nova Bay (Figures 1 and 2) is maintained solely by strong katabatic winds that blow sea ice offshore, and the blocking effect of the Drygalski Ice Tongue that prevents sea ice drifting in from the south (Figure 2). However, observational and modelling studies indicate that the concentration of the pack ice outside the polynya also plays a role in the dynamics of the Terra Nova Bay polynya [Van Woert, 1999a, 1999b; Jeffries et al., 2001].

For example, in May 1998 when the RVNBP operated briefly in Terra Nova Bay, it was almost completely covered with consolidated ice despite strong westerly katabatic air flow [Jeffries et al., 2001]. There was only 5% open water in Terra Nova Bay, where >50% of the ice was <0.15 m thick, and there was a strong west-east ice thickness gradient (Figure 6). The extensive ice cover was attributed to the blocking effect of the compact pack ice that prevented the ice in the bay from being advected eastward under the influence of the strong westerly air flow. Despite the almost complete ice cover, the area-weighted heat flow from the ocean to the atmosphere in Terra Nova Bay (~200 W m^{-2}) remained considerably larger than that in the pack ice (30-40 W m^{-2}) [Jeffries et al., 2001].

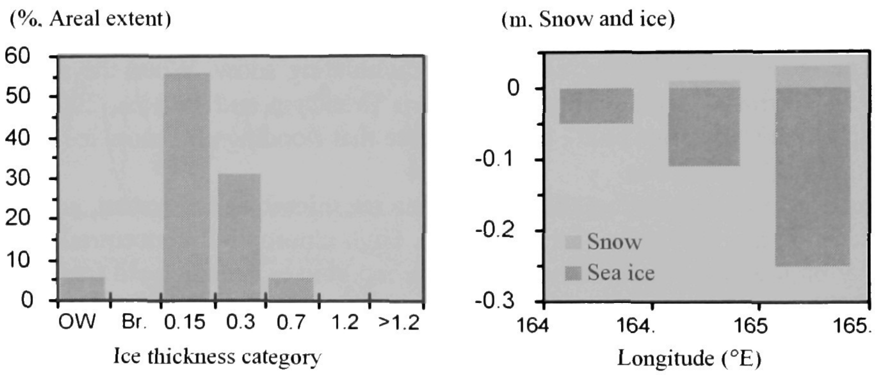


Figure 6. Areal extent of open water and different ice thickness categories (left) and mean thickness of unridged sea ice and snow depth (right) in Terra Nova Bay, 27-28 May 1998 [source: Jeffries et al., 2001]. OW: open water; Br.: brash ice; 0.3: ice 0-0.3 m thick; 0.7: ice 0.3-0.7 m thick; 1.2: ice 0.7-1.2 m thick; >1.2: ice >1.2 m thick.

Coastal polynyas such as that in Terra Nova Bay are often referred to as latent heat polynyas because the heat required to balance loss to the atmosphere, and hence to maintain the open water, is provided by the latent heat of fusion of continuous ice formation and removal. Because large quantities of sea ice are produced, polynyas are often referred to as "ice factories." The cumulative annual ice production in the Terra Nova Bay polynya has been estimated to be 50-80 km^3, about 10% of the total ice production on the Ross Sea continental shelf [Kurtz and Bromwich, 1985; Van Woert, 1999a].

The opening of the Ross Sea polynya (Figure 1) in winter was once attributed entirely to synoptic wind forcing [Zwally et al., 1985], but more recently it has been shown that an average of 60% of winter polynya events can be explained by katabatic winds blowing across the Ross Ice Shelf [Bromwich et al., 1998]. The winds blowing across the ice shelf might also play an important role in controlling the regional pack ice conditions that determine the dynamics of Terra Nova Bay polynya [Van Woert, 1999a, 1999b]. Thus, there is the intriguing possibility that the Terra Nova Bay and Ross Sea polynyas are closely linked, with physical interactions and feedbacks that could also have biological consequences [Van Woert, 1999a, 1999b]. This remains to be determined, and it would be an exciting and important investigation.

In austral spring, the Ross Sea polynya undergoes a rapid expansion as it opens northward and the Ross Sea pack ice begins to decay from within. Jacobs and Comiso [1989] suggested that the rapid springtime opening of the polynya might be due to ocean sensible heat, i.e., the ice melts in situ from below rather than being advected away by the offshore winds. Arrigo et al. [2000] also noted that, rather than being related to wind stress, the opening of the polynya in spring was more closely correlated with winter temperatures, which determine the ice thickness and thus its strength. Numerical simulations suggest that both wind stress and ocean heat contribute to the spring opening of the Ross Sea polynya [Fichefet and Goosse, 1999].

The question of the physical forcing that determines the polynya opening in spring is important because of the biological consequences. Beginning in November, the Ross Sea polynya becomes hyperproductive with the largest annual production of carbon in the entire Southern Ocean [Smith and Gordon, 1987]. Additional carbon production in the southwestern Ross Sea derives from a significant phytoplankton bloom in Terra Nova Bay [Arrigo and McClain, 1994; Arrigo et al., 1998b, 2000]. However, there are significant differences between the Ross Sea polynya and Terra Nova Bay blooms. The Ross Sea polynya bloom occurs a month or more earlier than the Terra Nova Bay bloom, and is dominated by the colonial prymnesiophyte Phaeocystis antarctica whereas the Terra Nova Bay bloom is dominated by diatoms [Smith and Gordon, 1987; Arrigo et al., 1998b, 2000]. It is thought that the later occurrence of the Terra Nova Bay bloom is due to a delay in the onset of surface water stratification, which occurs only after the katabatic wind intensity and frequency, and water mixing decline [Arrigo et al., 1998; Cunningham and Leventer, 1998].

DiTullio et al. [2000] have suggested that there is rapid and early export of the P. antarctica blooms to deep water and sediments in the Ross Sea. Since these and diatom blooms occur as the sea ice melts and retreats, the sediments contain a record of bloom dynamics in sea ice meltwater-influenced areas [Villinski et al., 2000]. There is strong spatial variability in modern diatom bloom composition and size in the Ross Sea that appear to be reflected in seafloor surface sediments; hence marine sediments core data could provide a record of palaeo-productivity and sea ice growth (perhaps so far as to identify whether the ice cover was dominated by frazil or congelation ice) and decay in the Ross Sea [Leventer and Dunbar, 1986; Cunningham and Leventer, 1998].

Gradients and Thresholds

There are a variety of physical gradients and thresholds in the sea ice of the southwestern Ross Sea. The following is a list of spatial gradients and thresholds, but it must be remembered that there is a temporal aspect to some or all of these phenomena. How the gradients and thresholds evolve through time is as important as their spatial location.

Gradients

- Continental shelf to deep ocean: pack ice thickness and snow depth.
- Coast to continental shelf: ice thickness and snow depth in polynyas and adjacent pack ice.

Thresholds

- Continental shelf and deep ocean: summer minimum and winter maximum in sea ice extent and area.
- Continental shelf to deep ocean: ice concentration; ice drift speed and deformation; ice formation and thickening.
- Coast to continental shelf: landfast ice thickness and formation versus pack ice thickness and formation; polynyas versus pack ice.
- Alongshore: landfast ice, ice tongues, polynyas.

Scientific Questions and Investigative Approaches

As I have prepared this description of the southwestern Ross Sea ice cover, a number of issues related to the current knowledge and understanding of sea ice and the Victoria Land Coastal Biome and their future study have presented themselves. The following list is not exhaustive, but I hope it serves as a starting point for the identification and discussion of key questions that deserve consideration.

1. Controls on the extent, thickness and modes of formation of landfast sea ice, their role in determining landfast ice ecosystem structure and productivity, and the contribution of landfast ice ecosystems to Ross Sea productivity;
2. Spatial and long term variability in the seasonal evolution of pack ice drift and deformation, ice thickness and snow depth, and ice formation and thickening processes on the continental shelf and the deep ocean;
3. The role of pack ice geophysical processes in shaping sea ice microbial community structure and productivity, phytoplankton blooms and marine productivity, and marine mammal ecology;
4. Magnitude and variability of interactions and exchanges between nearshore and offshore regions. For example, (1) controls on polynya dynamics (opening/closing), the magnitude of polynya ice production and export, and its contribution to pack ice mass, (2) the nature of the coupling, if any, between the Terra Nova Bay, Ross Sea and McMurdo polynyas, and (3) the role of polynyas in ice and ocean ecology and productivity;
5. The role of the marine environment in determining terrestrial physical and biological interactions and processes. For example, sea ice and ocean effects on continental precipitation and temperature variability, and the impact on terrestrial ecosystems and productivity.
6. Marine sediments, ice cores and other proxies of marine palaeo-environmental (physical and biological) variability and change: site selection, acquisition, analysis and interpretation.

The interdisciplinary investigation of the marine sector of the Victoria Land Coastal Biome will benefit from an integrated approach that involves in situ field investigations, remote sensing and numerical modelling. They can be used together to address questions about geophysical and ecological processes in the Ross Sea ice cover and ocean, and their role in atmosphere-ocean-continental interactions and exchanges.

Our current knowledge of Ross Sea ice physical and biological characteristics and processes has benefitted greatly from the availability of the RVNBP and its demonstrated ability to operate in the pack ice at almost any time of year. The RVNBP has supported, for example, the ROAVERRS (Research on Ocean Atmosphere Variability and Ecosystem Response in the Ross Sea) investigation of the Ross Sea ecosystem [Arrigo et al., 2000; DiTullio et al., 2000], southern Ocean JGOFS studies [Smith et al., 2000; Sweeney et al., 2000a, 2000b], and University of Alaska Fairbanks sea ice geophysics studies [Jeffries and Adolphs, 1997; Jeffries and Kozlenko, in press; Jeffries et al., 2001; Kozlenko and Jeffries, unpublished MS; Morris et al., unpublished MS]. Field programs are essential for process studies and validation of numerical models, and the RVNBP will play a vital role in in situ interdisciplinary investigations of the coastal and offshore sector of the Victoria Land Coastal Biome.

Time series of remote sensing data (1) support in situ studies, (2) allow scaling up from the local to regional scale, and (3) contribute to model validation. Ross Sea ice/ocean ecology studies have benefitted from satellite-derived ocean colour data [Arrigo and McClain, 1994; Arrigo et al., 1998]. Polynya studies have used NOAA AVHRR, and DMSP OLS & SSM/I (and other passive microwave data obtained by earlier instruments) [Kurtz and Bromwich, 1985; Zwally et al., 1985; Bromwich et al., 1998; Van Woert, 1999; Jeffries et al., 2001). Remote sensing data acquisition capability at McMurdo Station currently includes synthetic aperture radar (SAR), NOAA AVHRR, and DMSP OLS & SSM/I. Data from NASA EOS instruments and data acquired by foreign space agencies also will be important tools for Victoria Land Coastal Biome studies. Of particular interest from the point of view of sea ice geophysics and ecology are the NASA ICESat and ESA CryoSat instruments that will measure surface elevation from which it is anticipated that the total thickness of snow and sea ice will be derived. Of course, one need not only look at the ice from above. It is possible to look remotely at the ice from below, e.g., with moored upward looking sonar to derive information on ice draft, and ridge keel depth and frequency [e.g., Penrose, 1998].

Numerical modelling has considerable potential to contribute to the understanding of ecological and geophysical processes in the Ross Sea ice cover and ocean, and their role in atmosphere-ocean-continental interactions and exchanges in the Victoria Land Coastal Biome. There currently exist a number of physical and coupled physical-biological models that simulate small scale (ice floe) and regional scale Antarctic sea ice processes [Arrigo et al., 1993, 1998a; Fritsen et al., 1998; Maksym and Jeffries, 2000, 2001]. Terra Nova Bay and Ross Sea polynya dynamics and ice production has been simulated with some success [Darby et al., 1995; Gallée, 1997; Fichefet and Goosse. 1999;Van Woert, 1999a, 1999b]. Global and mesoscale models that provide insights into atmospheric processes and the climate of the Ross Sea region are also available [Bromwich et al., 1994; Hines et al., 1995, 1997]. While there is no doubt that modelling will contribute to the Victoria Land Coastal Biome investigation, it will require further model development, integration, application and validation.

Other Sources of Information

Remote Sensing Data and Research

- Arctic and Antarctic Research Center, Scripps Institution of Oceanography (http://arcane.ucsd.edu/)
- Alaska SAR Facility, University of Alaska Fairbanks (http://www.asf.alaska.edu)
- Remote Sensing of Ross Sea Ice and Ocean Ecology (http://pangea.Stanford.EDU/~arrigo/research.html)

Sea Ice Thickness Data

- ASPEct (Antarctic Sea Ice Processes and Climate [a program of SCAR GLOCHANT]) (http://www.antcrc.utas.edu.au/aspect/index.html)

Sea Ice and Ocean Buoy Data

- International Programme for Antarctic Buoys (http://www.antcrc.utas.edu.au/antcrc/buoys/buoys.html)

Antarctic Automatic Weather Stations

- University ofWisconsin, Antarctic Meteorology and Research Center (http://uwamrc.ssec.wisc.edu/aws/awsproj.html)

VICTORIA LAND ABSTRACT

Stacy Kim

Overview

Research in the Victoria Land Coastal Biome affords an excellent opportunity to study benthic community interactions in relation to gradations in physical, geological, chemical and biological factors such as sea-ice cover, seabed disturbance by ice scour, anthropogenic inputs, and planktonic production. A coupled biophysical model of transport and recruitment dynamics can be developed across the wide latitudinal gradient. The slow biological pace of Antarctic systems is potentially recorded in sponge spicule mats and in records created by ice formation. The availability of a long time series of ecological data and the impending shifts in McMurdo Station contamination levels make this a singular area for benthic research on disturbance recovery. The intense seasonal plankton bloom in Antarctica is likely tightly coupled to reproduction and feeding strategies of the benthos, in a system that is ideal for research on physiological pulsing.

Historical Data

A database on the benthic community structure in McMurdo Sound has been maintained since 1974 (Oliver 1980, Conlan and Kim unpublished data). Sampling areas include anthopogenically impacted sites near McMurdo Station, and pristine sites on both the west and east sides of McMurdo Sound. Impacted sites exhibit chemical contamination at an abandoned dump site in Winter Quarters Bay, and organic enrichment near the McMurdo Station sewage outfall (Lenihan et al. 1990, Lenihan 1992, Lenihan and Oliver 1995). The variety of sites allows assessment of the effects of different types of pollution on benthic communities in high latitude environments, and continued studies are timely because of the current installation of a sewage treatment plant at McMurdo Station. Data from the clean sites on either side of the Sound are suggestive of the relative importance of larval supply in defining community structures in this local area (sensu Dayton and Oliver 1977, Barry and Dayton 1988), a hypothesis that can be tested across a large scale along the Victoria Land Coastal Biome. From the existing data set, an analysis of long term trends is in progress in collaboration with Kathleen Conlan at the Canadian Museum of Nature and will be presented at the SCAR meeting in Amsterdam.

We have well-developed taxonomic expertise for the smaller benthic fauna of McMurdo Sound that has been complied in a guide by Kathleen Conlan. The guide is complete with photos that provide a rapid means to identify the often confusing diversity of animals from the McMurdo vicinity seafloor. This reference will be very useful to any ecologist studying benthic biodiversity along the Victoria Land coast. We are working towards integrating our guide with the photographic guide of macrofauna compiled by Norbert Wu and Peter Brueggeman and available at http://scilib.ucsd.edu/sio/nsf/fguide/index.html.

Temporal Changes

The time series of benthic data from the McMurdo area is unique. The high value of the data set can be maintained only by continuity, including in sampling techniques and taxonomic quality (i.e. Dayton and Oliver 1978). In addition, the installation of a sewage treatment plant at McMurdo offers an unprecedented opportunity for a large scale ecological experiment on organic enrichment in a high-latitude polar environment. McMurdo Station is the largest US base with over 1100 people during the summer season. The existing outfall is a large point source of organic enrichment (averaging 135,150 liters per day of untreated sewage); the new treatment plant will output a small fraction of this (pers. comm. F. Brier and B. Coppin). We (Kim and A. E. Murray) hypothesize that recovery rates following cessation of organic input, an unusual disturbance, will be much slower than benthic community recovery from typical seasonal ice-mediated disturbances (Lenihan and Oliver 1995). Through sampling the infauna over the period in which the sewage treatment facility is implemented, we can track the recovery of the infaunal community. In addition, we can use recent advances in molecular technology (e.g. Liu et al. 1997, Osborne et al. 2000) and understanding of the importance of the microbial biosphere to document recovery rates of this vital community component following both ice and organic disturbances, in tandem with the recovery of the infaunal community. The knowledge gained from this research could be applied to any situation of high organic loading in polar habitats, and would significantly further the understanding of anthropogenic impacts in polar environments using an integrated approach to evaluate the recovery of the microbial, microfaunal, and macrofaunal assemblages after a massive carbon loading perturbation sustained over 10 years.

A longer historical record of benthic community structure can be obtained from deposited sponge spicules on the seafloor, and in "dirty ice" that contains relict benthic communities uplifted by anchor ice (Dayton et al. 1969, Bockus 1999) or brought to the surface by the dynamics of ice movement. Fossil sponge spicules can be dated back to the Cambrian (Xiping and Knoll 1996, Brasier et al 1997, Zhang and Pratt 2000), and the thick mat now commonly found on the seafloor in the Antarctic is a record of sponge communities, though it is unknown how far back in time it extends (but see Leys and Lauzon 1998). Similarly, the zones of "dirty ice" found near permanent ice shelves contain intact benthic communities that have been trapped in forming anchor ice and lifted from the seafloor to the bottom of the ice layer. The gradual ablation of the surface ice progressively exposes these complete snapshots of the benthos. In areas where glaciers come into contact, large sections of the seafloor can be ploughed to the surface (e.g. Bratina Island), providing a record of the deeper benthic community. Though I have not fully developed the concepts, this approach has great potential for providing a long record of benthic ecology that can be linked with available pelagic and climatic records.

Spatial Changes

The latitudinal gradient in duration of open water, light intensity/daylight length (Grebmeier and Barry 1991), and seabed disturbance from ice (sensu Conlan et al. 1998) should create a gradient in benthic community composition. A straightforward distributional study recording basic population characteristics that can be correlated with environmental gradients is a necessary baseline (sensu Clarke and Crame 1992, Clarke 1996). We have formulated a preliminary hypothesis: Suspension feeders are the most responsive to seasonal productivity peaks, and deposit feeders respond more to total annual productivity. Active suspension feeders may be the most efficient at utilizing the intense food pulse, but their high metabolic requirements may not be sustainable through the rest of the year in areas with short productive seasons. Superimposed on the overall latitudinal gradient are "pockets" in bays where the ice does not go out as early, giving us a way of testing the hypothesis beyond simple correlation, though advected production must also be considered. Stable isotopic analysis of C and N along the Victoria Land coast (sensu Conlan et al. 2000) may define a gradient in food supply from in situ to advected sources.

The benthic marine environment in McMurdo Sound is characterized by marked differences between the biologically rich East Sound and the depauperate West Sound (Dayton and Oliver 1977). Limited previous observations of currents in the area (Gilmor et al. 1960, Barry and Dayton 1988, Dunbar and Leventer 1991) lead to the hypothesis that this pattern is driven by an inflow of oceanic water on the eastern sound, carrying an abundant supply of larvae, and a return flow of larvae-poor waters from under the permanent Ross Ice Shelf along the western side of the sound. We (Kim and C. V. Lewis) propose to investigate this hypothesis using a combination of physical and biological measurements of the oceanographic system to resolve larval supply and recruitment timing. A simple coupled biological-physical model (sensu Lewis et al. 1994) will be used to synthesize the results of the initial work, resolve the major pathways of larval transport and identify areas for future study. This research would lead to better fundamental understanding of the processes controlling benthic ecosystems under seasonal and permanent ice cover and produce a basic numerical model of the regional ecosystem.

Sentinels

Indicator species that respond rapidly to climate conditions must reproduce within the timespan of the relevant environmental change. In the benthos, this rules out the obvious large sponges and other long-lived organisms like the urchins and stars. We should focus instead on the opportunists, such as some of the small polychaetes and amphipods and the sponge *Homaxinella balfourensis* (Dayton et al. 1974, Dayton 1989).

Indicator species that provide a long record of growth in skeletal structures (e.g. scallops, Berkman 1997) provide potential to detect community responses to climate shifts over a longer time frame. The deeper water gorgonians and corals may offer sufficient skeletal material to track isotopic changes reflecting environmental shifts (sensu Dayton 1989, Aharon 1991, Bemis and Geary 1996).

Integration

The Victoria Land Coastal Biome offers a rich educational opportunity to all levels of students. The surging popularity of tele-teaching (e.g. the Jason project) as well as smaller scale interactions with local schools and classes via email and pre- and post-field presentations can reach K-12 levels. Undergraduate students can utilize data and specimens to complete senior theses or keystone projects. Field courses such as "Integrative Biology and Adaptation of Antarctic Marine Organisms" target graduate level students. Interactive exhibits at museum and media sites share progress and excitement of discovery with the general public. My activity at all these levels ensures the broadest dissemination of information and offers wide educational opportunities to students of any age.

SPATIAL AND TEMPORAL CHANGES IN THE ROSS SEA PHYSICAL ENVIRONMENT SINCE THE LAST ICE SHEET RETREAT

Kathy Licht

Ice sheet retreat from the Ross Sea continental shelf set the stage for modern environmental and ecosystem characteristics along the Victoria Land Coast. The transition from grounded ice cover to seasonally open marine conditions permitted colonization and ecosystem development in the marine realm and significantly altered the terrestrial ecosystem. Sedimentologic and seismic data indicate that grounded ice covered most of the continental shelf except the region north of Coulman Island during the last glacial maximum (e.g., Denton et al., 1989; Domack et al., 1999; Licht et al., 1996,1999; Shipp et al., 1999). Radiocarbon dates on the acid-insoluble organic (AIO) fraction of sediment indicates that ice sheet retreat began approximately 11.5 ^{14}C ka and retreated past Terra Nova Bay at ~10 ^{14}C ka (e.g., Domack et al., 1999; Licht et al., 1996). Terrestrial and marine ^{14}C data suggest that the area surrounding Ross Island was free of grounded ice by ~6.5 ^{14}C ka (e.g., Hall and Denton, 1999; Licht et al., 1996). Some studies have concluded that an ice shelf was present during ice sheet retreat, but specifics such as when, where, and how big remain difficult to estimate. Ice retreat history implies a relatively slow transition in environments along the latitudinal gradient during the Early Holocene. However, there are still significant gaps in our understanding of the history of ice retreat along the Victoria Land Coast.

The Holocene was characterized by measurable climatic/environmental variability. Taylor Dome ice core records of δD show that the early-mid Holocene was as much as 2° C warmer than the last 6 ky (Steig et al., 1998). Methanesulfonic acid concentrations from Taylor Dome (Steig et al., 1998) and diatom records from the Ross Sea (e.g., Kellogg and Truesdale, 1979; Cunningham et al., 1999) both indicate increased sea-ice cover associated with mid-late Holocene cooling. Diatom reconstructions have been used to differentiate between periods when summer sea ice disintegration was from physical breakup (wind) versus melting (e.g., Cunningham et al., 1999). There is a clear need to better constrain the timing of the Holocene climatic changes and to determine the effects of this climatic variability on coastal outlet glacier fluctuations (Baroni and Orombelli, 1994).

Apparently contemporaneous sediments in the western Ross Sea show significant spatial variability in depositional environments. For example, sediments from cores NBP9501-39 and –31 contain green, diatom-rich mud with few pebbles and accumulation rates of 15-30 cm/kyr. Granite Harbor contains similar sediments but the accumulation rate is 250 cm/kyr (DeMaster et al., 1996) and the site represents the longest high-resolution record identified thus far in the western Ross Sea. In contrast, core NBP9401-22 contains a pebble-rich diamicton with <1cm thick green, organic-rich layers. Holocene sediment accumulation rates for this core are 60-200 cm/kyr. These differences suggest that significant ecological variability should be expected for a single time horizon and that, in places, the latitudinal gradient is overwhelmed by local conditions. In the modern environment, ice-rafted debris from outlet glaciers is deposited within a few tens of kilometers of the coast (Dunbar et al., 1985) but offshore gradients in sediment accumulation rates (which may shape development of benthic communities) are not well known. Given the paucity of core coverage in some regions of the coastline and serious issues about chronology, efforts should be focused on carefully mapping environmental variability through time, developing high-resolution records of environmental change, and identifying events to anchor chronological information. Discrete tephra layers exist in Ross Sea sediments and may serve as important time stratigraphic horizons with which to link marine and terrestrial records.

Outstanding questions that must be addressed to aid our understanding of environmental conditions and ecosystem development include:

- *CAN WE DEVELOP A MORE RELIABLE AND DETAILED CHRONOLOGY OF TERRESTRIAL AND MARINE ENVIRONMENTAL CHANGE?*
- *WHAT IS THE HISTORY OF VICTORIA LAND OUTLET GLACIERS THAT DRAIN INTO THE WESTERN ROSS SEA?*
- *WERE THERE ICE TONGUES (BESIDES DRYGALSKI ICE TONGUE) IN THE PAST THAT WOULD HAVE AFFECTED THE LOCAL ENVIRONMENT?*
- *HOW VARIABLE ARE MARINE SEDIMENT ACCUMULATION RATES? HOW DO THEY RELATE TO TERRESTRIAL ENVIRONMENTAL CONDITIONS AND HOW DO DIFFERENCES AFFECT BENTHIC COMMUNITIES?*
- *WHAT WERE THE ENVIRONMENTAL AND ECOSYSTEM CHANGES ASSOCIATED WITH HOLOCENE FLUCTUATIONS IN CLIMATE?*
- *SHOULD THE PERIOD OF EARLY-MID HOLOCENE WARMTH BE CONSIDERED AS A MODEL OF ECOSYSTEM RESPONSE TO FUTURE WARMING?*
- *WHAT IS THE DEPTH AND SHAPE OF THE WESTERN ROSS SEA FLOOR? ARE THERE DEEP BASINS BESIDES GRANITE HARBOR THAT POTENTIALLY CONTAIN HIGH-RESOLUTION RECORDS OF ENVIRONMENTAL CHANGE?*
- *WHAT HAPPENS UNDER LARGE ICE SHELVES?*

The Antarctic Research Facility at Florida State University houses cores collected from the western Ross Sea and maintains an online database of cores and samples that have been obtained (www.arf.fsu.edu). Their database shows that almost 500 cores and grab samples have been collected in the western and west-central Ross Sea.

FAST ICE MICROBIAL COMMUNITIES ALONG THE VICTORIA LAND COAST

Michael Lizotte

One of the most thoroughly studied microbial ecosystems on Earth is the nearshore, land-fast sea ice of McMurdo Sound, Antarctica (Lizotte, submitted). A selection of the studies that have been conducted on this system includes: physical ice structure (e.g. Gow et al. 1998), optical properties (e.g., Palmisano et al. 1987; Trodahl and Buckley 1990) protistan population dynamics (e.g., Grossi et al. 1984, Stoecker et al. 1998), primary production (e.g., Grossi et al. 1987, Arrigo and Sullivan 1994), bacterial abundance and production (e.g. Kottmeier et al. 1987), photosynthetic acclimation (e.g. Lizotte and Sullivan 1991, Robinson et al. 1997), biochemical composition (Palmisano et al. 1988; Nichols et al. 1989; Raymond et al. 1994), nutrient relationships (e.g. Priscu and Sullivan 1998; McMinn et al. 1999) and particulate flux from these communities (e.g., Leventer and Dunbar 1987). All of these processes have been described in detail for seasonal trends, due to the logistical support available from McMurdo Station and the ease of access to the fast ice (particularly during austral spring). This degree of seasonal detail is rare for Antarctic marine ecosystems. For example, we have only a few spot observations or transects for offshore pack ice systems in the Ross Sea.

Fast ice microbial communities have been studied at a number of other sites around the continent, almost always in the vicinity of established research stations at lower latitudes (ca. 67 to 75°S) than McMurdo Sound (ca. 78°S). In the Ross Sea, fast ice of Terra Nova Bay (ca. 75°S) has recently been described (Tison et al. 1998; Guglielmo et al. 2000). High resolution (ca. 1 km) remote sensing images (e.g. Arrigo and McClain 1994; Zibordi et al. 1995) imply that fast ice (100% ice cover during November-January) can be found in embayments along most of the coast of Victoria Land, extending farther offshore in three large, contiguous fast ice regions: 1) from McMurdo Sound to Drygalski Ice Tongue (ca. 78 to 75.5°S); 2) from Cape Washington to Coulman Island (ca. 74.5 to 73°S) ; and 3) along the northern coast of Victoria Land (ca. 71 to 70°S). I will review the literature on fast ice environment and the associated microbial communities around Antarctica to develop hypotheses regarding latitudinal gradients extending north from McMurdo Sound (ca. 78°S) and Terra Nova Bay (ca. 75°S) to the northern coast of Victoria Land (ca. 70°S).

A HIGH RESOLUTION $\delta^{18}0$ RECORD OF GROWTH BANDING IN ADAMUSSIUM COLBECKI: A PROXY FOR RECONSTRUCTION OF COASTAL SALINITIES AND CONTINENTAL TEMPERATURES ON ANNUAL TO CENTURY TIME SCALES

Kyger C Lohmann, Paul Arthur Berkman and Maria C. Marcano

Growth banding in the shell of a single specimen of *Adamussium colbecki* was sampled for $\delta^{18}0$ at high spatial resolution (~100 μm intervals) utilizing a computerized micromilling system. This specimen from Explorers Cove was measured, tagged (Tag 7) and released in 1986 and later captured in 1998. During this interval, approximately 6.3 mm of growth occurred which provides direct information on shell growth rate. Based on an analysis of growth banding, shells of this taxon have the potential of providing geochemical records of the environmental variation that occurred in the coastal setting of Antarctica on seasonal to decadal and century time scales.

Variation in shell carbonate $\delta^{18}0$ across a 35mm traverse ranges from +4.5 to +2.7‰ and exhibits a high frequency of change that correlates with annual or seasonal time scales (Figure 1). Given that present day shelf waters (~15m to >25m) exhibit only minor temperature variation on a seasonal scale, ranging from −1.7°C to −2°C, this environment is effectively isothermal; thus, variations observed in shell composition must be controlled dominantly by changes in seawater salinity. To ensure that shell

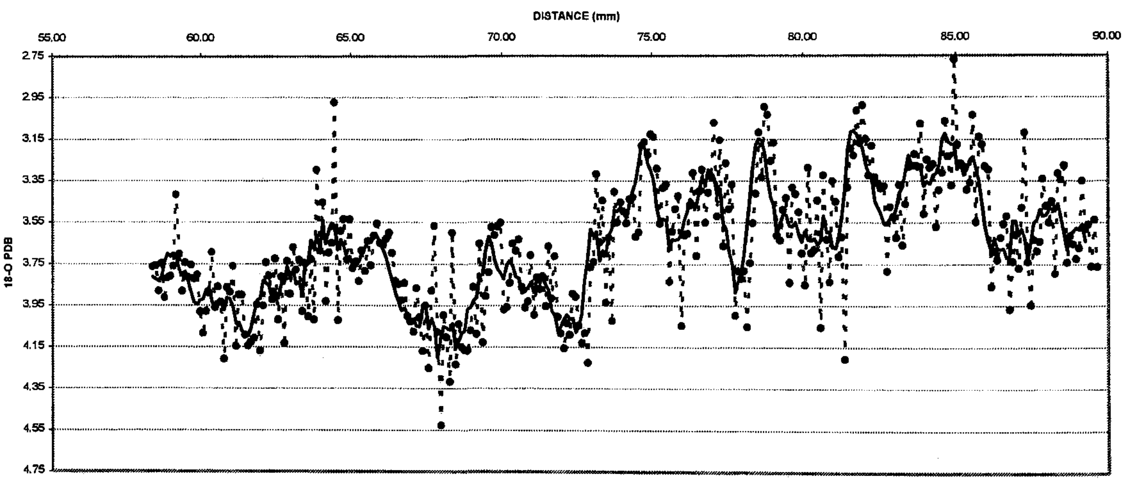


Figure 1. $\delta^{18}0$ variation of Tag 7 specimen of *Adamussium colbecki.* Dashed line and points represent individual analyses; trendline is a 5 point moving average. Based on correlation with long term air temperature measured at Orcados Sta., this record extends back to around 1910.

calcite is forming in isotopic equilibrium with ambient waters, the $\delta^{18}0$ of foraminiferal calcites encrusting the latest growth bands were also measured and these yield values averaging +3.7‰. Such values reflect calcite forming in waters at −1.0 to −0.7‰ $\delta^{18}0$, which are compatible with recent measurements of both water temperatures and salinities.

Examination of the high resolution record for the last 20mm of shell growth (Figure 2) demonstrates that annual patterns of $\delta^{18}0$ variation can be directly correlated to measurements of air temperatures measured at McMurdo Station (Figure 3).

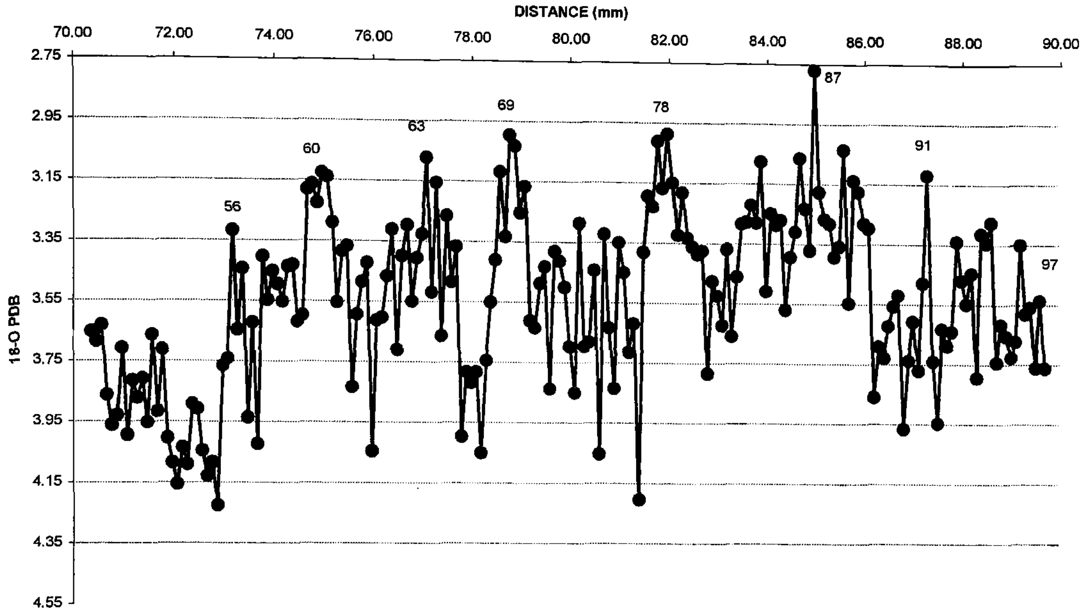


Figure 2. High resolution of Tag 7 illustrating annual scaled variations. Dates represent austral summers (i.e., 87 is 87-88) and have been assigned by correlation of major shifts in $\delta^{18}0$ toward more negative values and by number of such shifts between correlation points. Note that shifts in the baseline values (most positive values bounding years) records multi-year shifts in marine water salinities.

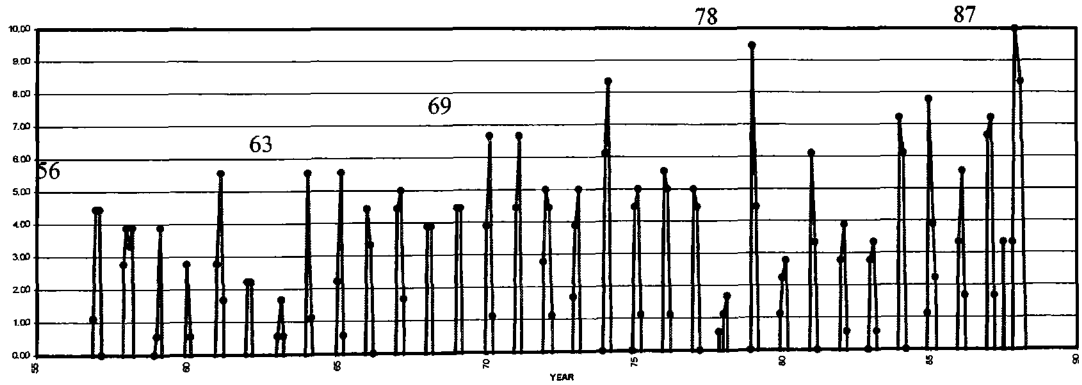


Figure 3. Variation in Maximum temperature (austral Winter) at McMurdo Station from 1955-56 to 1987-88.

Furthermore, the reflection of this pattern of change in shell carbonate must reflect primary changes in coastal water salinity in response to increased contributions of glacial meltwater (-30‰) during times of continental warming. Assuming that seawater temperatures are relative constant (-1.7 to 1.9°C), shell $\delta^{18}0$ values can be converted to the $\delta^{18}0$ of ambient seawater. Preliminary comparision of shell $\delta^{18}0$ values with measured maximum temperatures on a year by year basis provides a means of relating changes in coastal water $\delta^{18}0$ (in response to meltwater input) to changes in terrestrial temperatures.

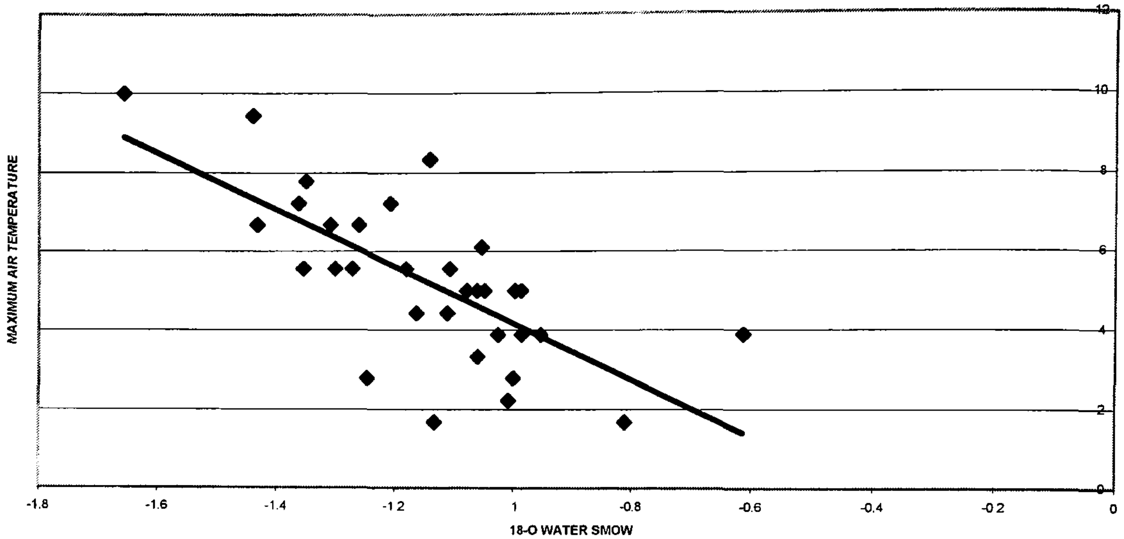


Figure 4. Correlation of Maximum Air Temperature and $\delta^{18}0$ water (calculated from shell carbonate at T=-1.8°C) shows a statistically significant correlation (R=.5).

This approach is strengthened by the large difference between meltwater and seawater $\delta^{18}0$ values, representing approximately a –0.9 ‰ $\delta^{18}0$ change per one part per thousand change in salinity. Thus, the calculated range in $\delta^{18}0$ water, from –0.6‰ to –1.7‰ reflects lower salinity limit of only 33ppt. Refinement of this relation can be accomplished through a more rigorous evaluation of the terrestrial temperature record, accounting for periods of extended warming, in contrast to an evaluation based solely on maximum annual values.

In conclusion, the high resolution $\delta^{18}0$ of shell carbonate derived from the Tag 7 specimen supports earlier assertions that this taxon exhibits exceedingly slow growth rates such that the life-span of an individual can preserve a geochemical record for the reconstruction of environmental variability on annual and decadal scales for periods extending over the last century. Of equal importance is the potential to utilize this marine record, for which abundant materials are available, to reconstruct the history of climate change in the adjacent terrestrial system.

VICTORIA LAND ABSTRACT

W. Berry Lyons

As the current lead PI of the McMurdo dry Valleys (MCM) Long Term Ecological Research (LTER) project, my research interests are in the areas of biogeochemical dynamics and the overall impact of climate change on the evolution of the terrestrial/aquatic ecosystems in the dry valleys. In addition, I have interest in the climatic history of Antarctica, especially during the Holocene. Our group has been responsible for the majority of the aquatic geochemical measurements for MCM-LTER, plus we, and our colleagues such as Bob Poreda, have used a number of isotopic tools to delineate the evolution of the lakes in Taylor Valley. Other areas of interest to our group include the rate of chemical weathering in polar climates such as MCM, the chemical evolution of terrestrial waters in the dry valleys and the controls of glaciochemistry of the alpine glaciers in the region. In order to help place the MCM-LTER data in context, a regional approach to both current and past ecosystem condition is needed. The legacy of past climates have an enormous impact on current ecosystem structure and function as well as biodiversity in the valleys. What would be considered subtle variations in climate parameters in temperate regions have had very important effects on the dry valley ecosystem. How do these climatic variations manifest themselves at other latitudes along the Victoria Land Coast? And how have the ecosystems responded? Can we better document decadal and millennial scale climate and ecological change along the Coast? These are important questions that this type of Workshop could help focus on.

McMurdo Long Term Ecological Research (LTER) Website: http://huey.Colorado.EDU/LTER/

THE INTERNATIONAL TRANS ANTARCTIC SCIENTIFIC EXPEDITION (ITASE) CHALLENGE

Paul A. Mayewski, Chair ITASE

ITASE

While the existence of a complex global environmental system is now recognized, its functional details are still poorly understood. In the Northern Hemisphere and portions of the Southern Hemisphere direct observational and instrumental records exist only for the last ~2000 and ~100 years, respectively, and, except at isolated sites, observational and instrumental records in Antarctica cover only the last 30-40 years. In addition, the relatively limited information available for past climate illustrates how little confidence we can place in the spatial uniformity of climate over the past few centuries.

Antarctica exhibits significant regional contrasts in its present-day climate regime. Evidence from instrumental records suggests some decoupling of climate change, even on decadal and finer scales, among different parts of the continent. Large areas of the interior of the ice sheet are influenced by the continental temperature inversion, while other portions of the interior and the coastal regions are influenced by cyclonic systems circulating around the continent. As a consequence, these peripheral areas are mainly connected with lower tropospheric transport, whereas high altitude areas in the interior are more likely influenced by vertical transport from the upper troposphere and stratosphere. High frequency complexity in climate is manifested through Antarctic synoptic systems. These systems vary interannually in response to major features of the atmospheric circulation system such as the El Nino Southern Oscillation (ENSO), the Antarctic Circumpolar Wave (ACW) and other regional- to global-scale factors, such as atmospheric blocking, sea ice variations and volcanic-induced insolation shielding, operating on weekly and greater time scales.

ITASE is a collaborative effort including 15 nations, organized under the auspices of IGBP and SCAR (Scientific Committee on Antarctic Research), whose challenge is:

(1) To determine the spatial variability of Antarctic climate (eg., accumulation rate, air temperature, atmospheric circulation) over the last 200 years, and where the data are available the last 1000 years.

(2) To determine the environmental variability in Antarctica over the last 200 years, and where available the last 1000 years.

US ITASE

US ITASE is effectively a polar research vessel. It offers the ground-based opportunities of traditional style traverse travel coupled with the modern technology of GPS, crevasse detecting radar, satellite communications and multi-disciplinary research. By operating as a ground-based transport system US ITASE offers scientists the opportunity to experience the dynamic environment they are studying. US ITASE also offers an important interactive venue for research (currently ten integrated science projects) similar to that afforded by oceanographic research vessels and large polar field camps, without the cost of the former or the lack of mobility of the latter. More importantly the combination of disciplines (meteorology, remote sensing, geophysics, surface glaciology, ice core glaciology, atmospheric chemistry) represented by US ITASE provides a unique, multi-dimensional (x, y, z and time) view of the ice sheet and its history. Ultimately, US ITASE will sample the physical and chemical environment over spatial scales in excess of 3000 km and up to 3000 m depth, over time periods of several hundred years (sub-annual scale) to hundreds of thousands of years (millennial scale) covering much of West Antarctica. US ITASE offers the capability for expansion of its activities into East Antarctica.

Major scientific and logistical accomplishments for the 1999-2000 (shakedown) and 2000-2001 (full) US ITASE field seasons:

1. Traverse vehicles (Tucker SnoCat, Challenger 55) covered a total of 2900 km (500 in 1999-2000; 2400 in 2000-2001). This represents 1200 km for the scientific traverse and an additional 1700 km required for shuttling of loads after the Tucker SnoCat engine failed during the 2000-2001 season. A new Challenger 55 is expected to replace the Tucker SnoCat in 2001-2002 or 2002-2003.
2. Continuous radar observations were made over 1200 km (300 for 1999-2000; 900 for 2000-2001) of the traverse route.
3. Ten science stations were occupied for periods of 2-9 days depending upon workload per site (three in 1999-2000; seven in 2000-2001). Science stations are sites where snowpits, 200+ ice cores, precision GPS, atmospheric studies and various other surface measurements are conducted.
4. Reconnaissance for the proposed inland WAIS deep drilling site was accomplished.
5. A total of 844 m of ice core (180 m in 1999-2000; 664 m in 2000-2001) were recovered.
6. Ten 2m snowpits were sampled for chemistry, stable isotopes, density and stratigraphy (three in 1999-2000; seven in 2000-2001).
7. Pemeability and porosity experiments were conducted from four snowpits and three ice cores (two in 1999-2000; two in 2000-2001).
8. Twenty-one days of atmospheric chemistry observations were conducted at seven sites (2000-2001).
9. Observations were made for purposes of ground truthing for satellite imagery.
10. Three automatic weather stations were deployed (2000-2001).
11. Ten high precision GPS 'coffee can' experiments were deployed to measure mass balance (three in 1999-2000; seven in 2000-2001).

ANTARCTIC MULTI-DECADAL SCALE VARIABILITY OVER THE LAST 500 HUNDRED YEARS

Paul A. Mayewski

High resolution ice core environmental records from, South Pole and Law Dome (East Antarctica) and Siple Dome (West Antarctica) have been calibrated with instrumental series of sea level pressure and sea ice extent to develop proxies for the latter.

The robust spline component of the MS record from South Pole is significantly correlated with sea ice extent in the Amundsen-Ross Sea (A-RS) region and the residual MS series is significantly correlated with the frequency of El Nino events (Meyerson et al., in review).

The annual seasalt record developed from the Law Dome ice core is significantly correlated to June mean sea level pressure across a broad area of East Antarctica and adjacent regions of the Indian Ocean sector of the Southern Ocean (DSL) (Souney et al., in review).

The annual seasalt record from Siple Dome is significantly correlated with variability in the Sept-Nov behavior of the Amundsen Sea Low (ASL) and Sept – Nov sea level pressure in adjacent regions of the Pacific Sector of the Southern Ocean (Kreutz et al., 2000).

Comparison of ice core proxies for sea level pressure and sea ice extent, the Law Dome stable isotope and carbon dioxide records, and the tree ring 14C residual series over the last 500 years reveals interesting associations that are important in understanding Antarctic multi-decadal scale climate variability. Notably:

(1) The ice core record demonstrates impact of the ENOS phenomena at South Pole.
(2) The Davis Sea Low (DSL) deepens and migrates east when Law Dome temperatures decrease,
(3) DSL and ASL behavior is similar over the last 500 years,
(4) Major breaks exist in all records near the end of the Maunder Minimum (1750-1800),
(5) All records reveal 20-30, 35-40 and 80+ year periodic behavior suggesting similar climate forcing.
(6) Strong associations exist between the 14C proxy for solar variability and major climate events in the Siple Dome record (Kreutz et al., 1997), and the proxies for atmospheric circulation, temperature, and sea ice from South Pole and Law Dome records.

USING GIS TO DEVELOP GEOSPATIAL DATASETS FOR UNDERSTANDING ENVIRONMENTAL PROCESSES IN THE VICTORIA LAND, ANTARCTICA, COASTAL BIOME

Carolyn J. Merry

Summary

A Geographic Information System (GIS) offers an excellent potential for providing a database of space-time information for the Victoria Land, Antarctica, coastal biome. A GIS is best described as "a system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth" (Dueker and Kjerne, 1989). In the past traditional methods have been used to analyze map data one layer at a time, involving tedious hours in map composition and compilation. With a GIS many data layers are organized and stored together in the computer using automated methods. The data layers are georegistered using software utilities and then are subsequently used in analysis and modeling routines to produce final results and maps.

A GIS is composed of four basic subsystems: data input, data storage and retrieval, data manipulation and analysis, and a reporting system (DeMers, 2000). The *data input* subsystem is used to collect and preprocess spatial data from various sources, which can include remote sensing data, field-sampling data, or from existing digital data sources. Data conversion routines are available to scan or digitize analog maps for input to a GIS. The *data storage and retrieval* subsystem allows for the data layers to be stored in a common format database that organizes the data, allowing the map layers to be queried and retrieved for editing and updating and for expansion purposes. The *data manipulation and analysis* subsystem allows for data conversion and to perform analytical and modeling functions on the map layers. The *reporting* subsystem can be used to display part or all of the data in the form of maps, tables, graphics or in a report format.

Basic data structures of raster and vector format are used in a GIS. *Vector* data consists of points, lines, polygons or surfaces. *Raster* data are represented on a fixed grid (called grid cells or pixels) and is typically used for remote sensing data. The data characteristics that all GIS layers have in common include *space*, which is where features are located on the earth's surface. An *attribute* is used to identify the quality or characteristic of a feature. *Relationships between features* are described with topological relationships that include area definition, adjacency, connectivity and nestedness. A newer, nontopological data structure is the shapefile, which stores the geometry and attribute information for a geographic feature in a dataset that includes a main file, an index file, and a database table (DeMers, 2000). *Time* can also be considered as another spatial dimension in a GIS.

There is a wealth of information that can be used in a GIS. Remotely-sensed data would include back-and-white (panchromatic) aerial photographs, radar images, GPS-located data, sonar and LIDAR data. Biophysical or hybrid variables can be derived from color aerial photographs, multispectral data, hyperspectral data and multi-band radar imagery. Examples of these biophysical or hybrid variables include x,y geographic location, z topographic/bathymetric, vegetation (chlorophyll concentration, biomass (green and dead), foliar water content, absorbed photosynthetically active radiation (APAR), phytoplankton), surface temperature, soil moisture, surface roughness, evapotranspiration, atmosphere (tropospheric chemistry, temperature, water vapor, wind speed/direction, energy inputs, precipitation, cloud and aerosol properties), BRDF (bidirectional reflectance distribution function), ocean (color, phytoplankton, biochemistry, sea height), snow and sea ice (extent and characteristics), volcanic effects (temperature, gases), land use (urban infrastructure and land use), and vegetation (stress) (Jensen 2000). Conventional data sources are also available. These would include data derived from maps, statistical data from published tables, CAD drawings, archived data from the Internet, and the 4 Ds from the U.S. Geological Survey (DRG – Digital Raster Graphic, DLG – Digital Line Graph, DEM – Digital Elevation Model, and DOQQ – Digital Orthophoto Quarter Quad).

Remote sensing will be important for use in the Victoria Land study because of the remoteness of Antarctica. Remote sensing is defined as "the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface" (Campbell, 1996). Landsat (MSS and TM), SPOT, IRS, Ikonos, NOAA AVHRR, SeaWiFS, Radarsat, ERS and the NASA EOS suite of sensors (MODIS, ASTER, MISR, CERES, MOPITT) will be important sources of information about Victoria Land. These remote sensing sensors can provide historical, as well as current, datasets for the coastal biome environment. Incorporating temporal datasets into a GIS will be a challenge, but a necessity, for characterizing the coastal biome over time and space.

Data in a GIS can be of four types: nominal, ordinal, interval or ratio data (Chrisman, 1997). With *nominal* data, the objects are categorized or named into groups and assigned a class value. The class value numbers are related to names, such as tree species, soil types, or land cover. *Ordinal* data implies a rank or order to the data. For example, 1 could be classed as good, 2 as moderate, or 3 as poor. *Interval* data are placed on a number line with an arbitrary zero point and an arbitrary interval. The intervals between data values are meaningful and differences can be quantified. Example data would include soil temperature, elevation or degrees Fahrenheit. *Ratio* data measures have a true origin (zero value) and an arbitrary interval and proportions can be quantified. Example data would include electromagnetic radiation, rainfall, slope or degrees Kelvin.

A base map provides the geographic reference system to serve as the foundation for later rectification of additional map layers. The base map shows the spatial relationships between features and the geometric shape of the features. Coordinate systems are important in developing the base map. A geographic coordinate system (latitude/ longitude or decimal degrees) is recommended for small-scale research. A plane coordinate system (Universal Transverse Mercator – UTM or state plane coordinates) is recommended for large-scale research. Considerations for selecting the coordinate system and the map projection for the base map are important, as the base reference system serves as the foundation for additional map layers supporting the various research activities.

GIS analysis tools are used to derive spatial relationships from the data layers. Examples of a GIS analysis tool that can be used for understanding and modeling environmental processes include *inventory* operations. Such operations include measurement of distance, area and size, and perimeter of an object. *Spatial queries* include a graphic query of objects in the database or a Boolean operation, such as AND, NOT, OR or XOR, that can be used to query two or more map layers. *Database operations* include lists or reports extracted from the relational database.

Other spatial analysis tools that would typically be used in the Victoria Land study would include buffer and overlay operations. *Buffer* operations are used to create zones at a specified distance that surround a point, line or an area feature. The buffer is created based on the location, shape and orientation of the object. The buffer can also be incremented at multiple distances from the feature object. *Overlay* operations occur when one map layer is overlain on another. Algebraic operations, such as ADD or MULTIPLY, are performed to result in a new map data layer. With an overlay operation, the newly-created overlay map may need to be further processed to "clean up" the data layer. Such operations include dissolve, merge, clip, intersect or union.

Network analysis may also be important for application to the Victoria Land study. Networks are comprised of links (line entities) that are connected with the link attributes sharing a common theme, primarily related to flow. Examples include transportation networks or a stream network. Networks would allow modeling of flow throughout the Victoria Land area or could be used to track the movement of animals along a corridor.

Three-dimensional analysis allows us to analyze spatial information from a 3-D perspective. This is important for visualization purposes of the database and for conducting terrain analysis. Products from a terrain analysis include viewsheds, slope, aspect, hillshading, elevation, and watershed maps.

The *space-time* concept in GIS allows us to model spatially-related events using time (t) as one dimension in space. The correlation between spatial movement and time can be derived by using conventional mathematical functions, such as distance, which is calculated in three dimensions. For example, distance, velocity and space-time distance can be represented, respectively, as:

$$\text{Distance } [\ ]_{x,y,t} = \text{sqrt}\, [\, x^2 + y^2\,]$$
$$\text{Velocity } [\ ]_{x,y,t} = \text{sqrt}\, [\, x^2 + y^2\,] / t$$
$$\text{Space-Time Distance } [\ ]_{x,y,t} = \text{sqrt}\, [\, x^2 + y^2 + t^2\,]$$

A proposed distributed computing environment for database storage, data integration and data sharing across universities, and even countries, is recommended for the Victoria Land study. This allows for distributed analysis of the datasets and promotes team collaboration. The GIS should be able to handle a wide variety of datasets. Datasets that are developed from field activities, traditional map sources and remote sensing data should be archived and then distributed through various media. The data distribution policy should be "open" and provide for public access.

In summary, a GIS is recommended for providing a database framework for storing, analyzing and archiving space-time information for the Victoria Land, Antarctica, coastal biome.

VICTORIA LAND ABSTRACT

Daryl Moorhead

My primary interests in Antarctic research are development of population, nutrient cycling and energy flow models (see below) for soil, stream and lake ecosystems, in addition to further developing the legacies concept for the dry valley system.

1. Modeling population dynamics of key organisms in dry valley soils. For example, a recent model was developed to simulate population dynamics of the nematode, Scottnema lindsayae, in dry valley soils as a function of temperature.

2. Controls on phytoplankton production in dry valley systems. For example, a recent effort examined the location of deep chlorophyll maxima in lakes of the dry valleys; one overview focusing on five lakes within the Taylor and Wright Valleys and one focusing on the double DCM in East Bonney.

3. Sensitivity of production patterns to light regime and respiration for benthic microbial mats in dry valley lakes.

4. Patterns of energy flow through plankton food webs of Antarctic lakes. This project developed through collaborations with Dr. Johanna Layborn-Parry. Additional data have been provided for Crooked Lake and Ace Lake to support a broader modeling synthesis.

5. Nitrogen transformation in dry valley streams. Several studies are being combined into a general synthesis of N-transformation in dry valley streams, starting with the previous work of Howard-Williams, Vincent and Priscu, focusing on Canada Stream. This work was combined with data from the first McM-LTER stream tracer study to develop the initial N-transformation model, and will be tested against existing data from studies of the Onyx River made by New Zealand researchers.

6. Resource legacies link biological communities across time and space in the dry valleys. In addition to further development of the long-term legacies conceptual basis for millennial scale dynamics in dry valley landscapes, recent data suggest shorter, decade scale cycles in organic matter production and distribution over smaller spatial scales.

McMurdo Long Term Ecological Research (LTER) Website: http://huey.Colorado.EDU/LTER/

THE ITALIAN ANTARCTIC METEO-CLIMATOLOGICAL OBSERVATORY

A. Pellegrini

Our activities started in 1986, when the first Automatic Weather Station was installed (Argos ID 7353, see Fig. 1). Since then, 10 more AWS's were added and a radiosounding station is also operated during summer. Fig. 1 shows where the Stations are located, while Tab. 1 also describes which sensors are installed on each datalogger.

The Stations are active year-round and data are stored each hour on a local solid-state memory. Also, data are transmitted through the Argos CLS System, which provides almost-real time service. Most AWS's were installed between 1988 and 1990: data are available since then on a database which will be soon on a Web site for anonymous FTP.

For future activities related to the Victoria Land Project, some additional sensors can be added to the AWS's, depending on the fundings that will be made available from the National Programme: we are fully open to suggestions (UV sensors, ground temperature ...).

At Terra Nova Bay Station, an HRPT receiving station is also operated: it is not under the responsibility of the Observatory, in any case satellite images can be made available to the Victoria Land Project: acquisition started in 1990 with NOAA satellite, later (1997) also DMSP images were received and archived. Imagery retrieving and processing might require some extra resources, as it is not stored in a proper database, only raw data tapes are available.

The Observatory works in very close conjunction with Operational Meteorology at TNB Station: if necessary, past ECMWF weather analyses and maps can be retrieved from the European Centre database, while during summer, a selection of present and forecast meteorological fields are regularly received at Terra Nova Bay Station.

Therefore, during the planned Campaign(s), some additional assistance can be provided by Terra Nova Bay Station, such as:

- specific weather forecasting and meteo assistance;
- satellite-derived ice maps;
- ...

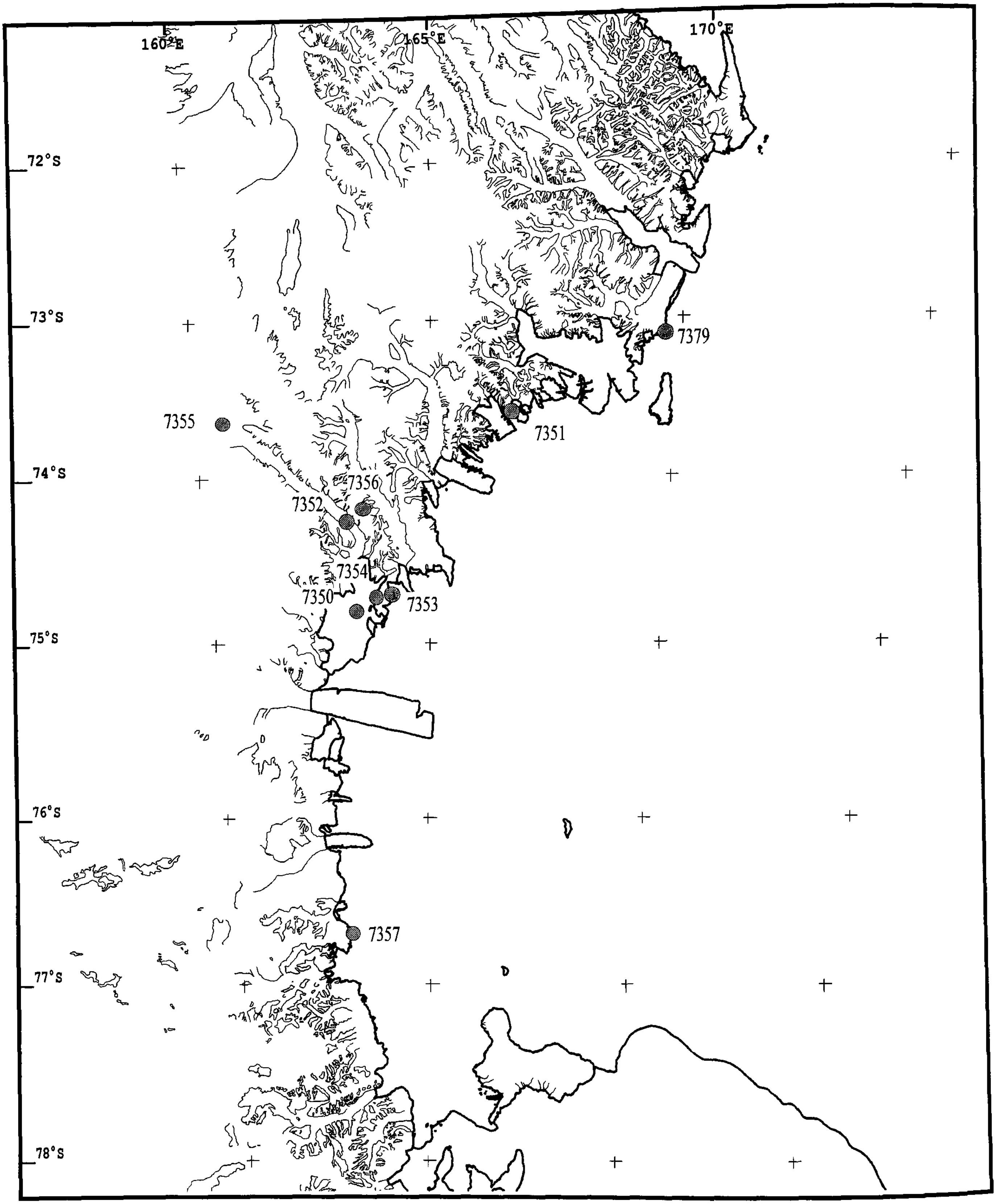


Figure 1. Location of Automatic Weather Stations

Table 1. List of AWS's

ARGOS ID (Name)	Geographic location	Latitude	Longitude	Height (m)	Sensors[1]
7350 (SOFIA)	NANSEN ICE SHEET	74° 48' S	163° 19' E	40	P T RH V
7351 (ALESSANDRA)	CAPE KING	73° 35' S	166° 37' E	160	P T RH V RAD[2]
7352 (ZORAIDA)	PRIESTLEY GLACIER	74° 15' S	163° 10' E	640	P T RH V
7353 (ENEIDE)	TERRA NOVA BAY	74° 42' S	164° 06' E	90	P T RH V RAD[3]
7354 (RITA)	ENIGMA LAKE	74° 43' S	164° 02' E	210	P T RH V
7355 (MODESTA)	PRIESTLEY NÈVÈ	73° 38' S	160° 39' E	1900	P T RH V
7356 (LOLA)	TOURMALINE PLATEAU	74° 08'S	163° 26' E	1700	P T RH V
7357 (ARELIS)	CAPE ROSS	76° 43' S	162° 58' E	150	P T RH V
7379 (SILVIA)	CAPE PHILIPS	73° 03' S	169° 36' E	550	P T RH V

[1] SENSORS LEGEND:
P = atmospheric pressure (hPa)
T = temperature (°C), about 2 m above ground level
RH = relative humidity (%), about 2 m above ground level
V = wind speed and direction, about 10 m a.g.l.
RAD = global solar radiation at ground (W/m^2).
[2] RAD since January 1989.
[3] RAD from February 1987 to Feb. 1988.

MARINE HIGH-RESOLUTION HOLOCENE ENVIRONMENTAL CHANGE RECORDS AND GEOLOGICAL PROCESSES FROM THE VICTORIA LAND COAST: ESTABLISHING A BASE-LINE FOR THE MODERN MARINE ECOSYSTEM

Ross D. Powell

Two marine geoscientific aspects can provide important data for ecosystem research along a latitudinal gradient of the Victoria Land Coast, Antarctica: the Holocene record as preserved in marine geological cores and modern geological processes. Such data sets can firstly provide a record of how modern ecosystems may have become established since the last glacial maximum, what temporal and spatial variability there may have been during their establishment, and at what rates glacial ice retreated and ecosystems became established relative to that retreat. Secondly, they establish a base-line for understanding some of the physical and chemical processes controlling modern marine ecosystems.

Quaternary successions from marine geological cores have been a recent focus for providing high-resolution records of past environmental changes in Antarctica to compare with those of the rest of the Southern Hemisphere and also the Northern Hemisphere, and on which future predictions may be based; they may also assist in deciphering natural variability from human-induced changes (e.g. Domack and Mayewski, 1999; Domack et al., 2001). We need to extend the data-base of high-resolution marine geological records of environmental change that have been established recently elsewhere in Antarctica to the Ross Sea sector. Such records can also provide the timing of when marine environments became available for biological communities following deglaciation of the Ross Sea and may also contain records of those communities as they became established and developed through time under the influence of changing physical and chemical conditions.

One location is currently be investigated for recovering such a record, that is in Mackay Sea Valley (MSV) which is believed to have been eroded by earlier expansion of Mackay Glacier, a major outlet glacier of the East Antarctic Ice Sheet. MSV extends through Granite Harbor and out to the western Ross Sea. Since being uncovered by glacial retreat, sediment appears to have accumulated in the deep basin at relatively high rates because this area is a site of intense biological activity. More such deposits need to be found in other deep basins to the north along coastal Victoria Land. Surveys need to assess the basins' potential for holding similar records which may then be used to assess latitudinal as well as temporal variability. The likelihood of such deposits is moderately high because drift deposits are being found in other deep basins on the Antarctic continental shelf (Leventer et al., 1996; Harris et al., 1999; Harris, 2001; Harris and Dunbar pers comms, 2001).

Such studies need to: 1) apply multi-proxy techniques to extract high-resolution (decadal(?) to century scale) Holocene records, 2) establish marine-terrestrial correlations with geological and ice core records both locally and from elsewhere in Antarctica (e.g., Dry Valleys and Antarctic Peninsula Quaternary geological records; Taylor and Siple Dome ice core records), and 3) test Antarctic variability with records from the Northern Hemisphere for cross-hemispheric comparisons. If sediment accumulation rates are high enough, then decadal-to-century scale records may be possible to extract from the cores. If so, then because this is in the Pacific sector of the Antarctic, evaluation of the linkage of the Antarctic to such cycles as the Pacific Decadal Oscillation (PDO) and the El Nino Southern Oscillation (ENSO) may be possible. They may also provide records of such atmospheric/oceanic processes as polynya, mid-column water mass circulation and bottom water production. These marine records should be linked to atmospheric records preserved in ice cores and the two types of records used to provide a strong, broad data-base for such assessments.

Our present knowledge of nearshore processes associated with glacial margins along the Victoria Land coast is very poor, especially relative to their influence on ecosystems. These need to be better documented both in terms of understanding modern ecosystems and their environmental controls, but also in providing models for interpreting older Holocene records discussed above. A study at the Mackay Glacier has shown how, using an ROV, epibenthic and infaunal communities can be documented in areas of floating glacier-tongues (Dawber and Powell, 1998). Communities can be related to glacial and marine processes that influence their structure. The study was also able to documented recent decadal environmental changes due to glacial retreat and creation of new ecological niches. More studies of similar type are needed along different sectors of the Victoria Land coast.

These types of studies also provide cross-disciplinary linkage between the Antarctic Ice Margin Evolution (ANTIME), International Trans-Antarctic Scientific Expedition (ITASE) and Antarctic Sea-ice Processes and Climate (ASPeCt) programs of SCAR's Group of Specialists on Global Change and the Antarctic (GLOCHANT).

VICTORIA LAND ABSTRACT

John C. Priscu

My research over the past 20 years has focused on the interaction of microorganisms and their environment. By nature, such research must be interdisciplinary. I believe that interdisciplinary research, if properly conducted, can move beyond the bounds of discovery, increasing the explanatory power, immediate relevance, and practical application of research to complex, real-world problems. My experience has revealed that few researchers or institutions have meaningful experience with its actual practice. Most researchers have been raised, and continue to participate in the tradition of disciplinarity and departmentalism. In fact, though scientists and funding agencies use the term "interdisciplinary" extensively, strong institutional bias against interdisciplinarity exists at most universities. Since obtaining my degree in Ecology, I have attempted to work with experts in many fields to address environmental questions. Clearly, no single person has the knowledge to address individual fields effectively; a concerted interdisciplinary effort is required to address the complex questions that face us. Importantly, my experience has shown that advances in interdisciplinary research depend to a large degree on the naivety and serendipity that accompanies such an approach.

The Victoria Land Coast (VLC) program offers a venue for true interdisciplinary research. By examining a terrestrial/marine gradient across an ecologically compressed range of latitudes (i.e., high latitude) we should be able to address important ecological issues regarding climate change (past and future), land-water interactions, and ecosystem legacy, and cast them in a global context. My interests in the project focus on microbial ecology in extreme environments, i.e., how do microbes survive, multiply and interact within and between environmental ecotypes. I have studied and published research articles during my 17 years of polar research on soils, lake water, lake ice, glacial ice, sea ice and sea water within the McMurdo area. Most of my publications have focuses to a large extent on climate driven variability. Over the years, my interests have expanded to the point where I now label myself as an ecosystem scientist. The VLC program would cast me with an excellent group of scientists having similar interests. Examples of research interests can be found on my website (http://www.homepage.montana.edu/~lkbonney). In particular, refer to the recent ecosystem based publications I edited for Bioscience and AGU.

VICTORIA LAND ABSTRACT

Reed Scherer, Charlotte Sjunneskog and Ala Aldahan

Diatom fossils can provide paleoenvironmental proxies for both marine and non-marine environments along the Victoria Land Transect. They represent a very wide variety of aqueous habitats, including (1) fresh, brackish and hypersaline lakes, ponds, and streams along the coast and on ice shelves, (2) littoral marine habitats, sea-ice habitats, marginal marine habitats, and open marine habitats. Each of these habitats contains a distinctive set of diatom assemblages, and diatom fossils preserve well in these settings. Consequently they can provide powerful tools for elucidating late Holocene environmental history along the Victoria Land Transect. Wind-blown diatoms are also useful, in a qualitative way, as tracers in ice cores for past wind direction and availability of eolian sources of exposed, desiccated aqueous sedimentary deposits.

Diatoms are not the only primary producer in these settings. Several other alga may contribute, but many of these do not preserve fossil records. Therefore, diatom data may be supplemented with geochemical tracers that suggest past productivity. These include organic carbon and barite crystals produced in the water column by the decay of biogenic materials. We have successfully correlated barium content with diatom producers in Ross Sea sediments. It is unclear at present whether biogenic barite is present in lakes, or whether it could be used as a proxy for past productivity in the lakes.

The primary limitation for the application of diatom data toward integrated Holocene paleoenvironmental analyses in the Antarctic is time control. Radiocarbon provides the best available source for chronological information from Holocene sedimentary records, but, as is well-documented, there are numerous complicating factors associated with applying a radiocarbon chronology to Antarctic marine and non-marine sediments.

Our program aims to contribute expertise toward generating paleoenvironmental proxies from diatoms and geochemical tracers in sediment cores from marine and non-marine settings along the Victoria Land Transect. The objective would be to successfully correlate these records, and to integrate the interpreted climatic events into a regional paleoenvironmental picture. Emphasis will be placed on latitudinal and longitudinal gradients and events.

In addition, we will evaluate eolian diatoms in the Taylor Dome ice core, with the express purpose of attempting to correlate to local source areas (dry valley lakes, coastal ponds, littoral flats, etc.).

VICTORIA LAND ABSTRACT

Bruce D. Sidell

I should start by stating clearly that I do not have a preconceived "vision" for interdisciplinary collaboration in the Victoria Land project. Nor am I completely certain about what would constitute valuable information to communicate in this "Abstract". I do, however, have definite interests in environment-organism interactions and how they affect the physiology of individual organisms, biogeographic distribution of species and, the evolution of traits. In initial discussions with Paul Berkman, it seemed that my own expertise and interests might permit me to engage productively in discussions at the workshop.

Research interests of my laboratory are aimed broadly at understanding how cold body temperature as an evolutionary force shapes the physiological and biochemical characteristics of living systems. This means that we are interested in both: 1. features of the physiology and biochemistry of cold-bodied organisms that are adaptations to life at cold body temperature and, 2. features of the physiology and biochemistry of cold-bodied organisms that are permitted by life at cold body temperature but that would be deleterious in other environments (*e.g.* warmer thermal regimes). Almost all of our work focuses on fishes, especially the notothenioid fishes of the Southern Ocean surrounding Antarctica. Our fieldwork in Antarctica during the past 15 years has been conducted in the Antarctic Peninsula area in the vicinity of Palmer Station and we have no direct experience at the High Antarctic Zoogeographic Zone of the Ross Sea. In addition to laboratory expertise with physiological and biochemical methods, we are experienced with shipboard deployed trawls and are experimenting this year with buoyed and anchored fish traps/pots.

Within the first category of characteristics above, *i.e.* adaptations, we have identified aspects of the metabolism, cellular and subcellular structure and biochemistry of Antarctic fish tissues that appear to help ensure normal cellular function at very cold temperature. Antarctic notothenioid fishes possess very high content of fats in their bodies, their energy metabolism of is highly aerobic, and their metabolism appears to be especially dependent upon oxidation of fatty fuels (Sidell *et al.*, 1995). Because oxygen is more soluble in fats than in aqueous compartments, the high fat content of tissues in Antarctic species also may enhance the rate of oxygen diffusion through tissues of these animals in at least partial compensation to the otherwise depressing effect of cold temperature on oxygen diffusion (Sidell, 1998; O'Brien and Sidell, 2000b). Aerobically poised muscle tissues of Antarctic fishes contain remarkably dense populations of mitochondria (up to ~50% of cellular volume), which provide a robust catalytic capacity for aerobic metabolism and also ensure a short diffusional pathway for oxygen within the cell (Londraville and Sidell, 1990; O'Brien and Sidell, 2000a). Evidence is also accumulating from work in ours and other laboratories that strongly suggests that evolution at cold body temperature has resulted in selection for protein structures that ensure maintenance of conformational flexibility that is important to enzymatic catalysis or binding of ligands (*e.g.* Fields and Somero, 1998; Cashon *et al.*, 1997).

A good deal of our recent work also has focused on an unusual group of Antarctic fishes that illustrate how the stable environmental extremes of the Southern Ocean, coupled with the unique evolutionary history of Antarctic fish fauna, have combined to permit the persistence of physiological traits that would probably have been eliminated by negative selection in any of the world's other marine habitats. These fishes are the Antarctic icefishes (Family *Channichthyidae*). They are probably best known because of complete lack of hemoglobin in their circulating blood, a feature unique among all adult vertebrate animals. We have demonstrated that at least 5 of the 15 known species of icefishes also lack the intracellular oxygen-binding protein, myoglobin (Mb) in their aerobic muscle tissues while at least 8 other produce this protein in heart muscle only (Moylan and Sidell, 2000). By mapping the trait of presence/absence of Mb on the best available phylogeny of the *Channichthyidae*, we conclude that ability to produce Mb has been lost through a minimum of 4 completely independent events during the evolution of the family. We also have been able to establish that these losses have occurred *via* at least 3 completely different mechanisms. Further experiments have established that, when present, Mb of icefishes functions well at their physiological temperature (Cashon *et al.*, 1997) and enhances the mechanical performance of their hearts (Acierno *et al.*, 1997). These observations seem incompatible with modern population genetics theory that would predict that, due to diminished viability and/or reproductive success, "disadvantageous" traits will be subject to negative selection and be eliminated.

We believe that paradoxical persistence of icefishes lacking normally critical oxygen-binding proteins may be due to two factors. The first of these is environmental. The very cold temperature and extensive vertical mixing of the Southern Ocean results in exceptionally high oxygen content throughout the water column. Metabolic rates of the animals are relatively low because of their cold body temperature. These features ensure that sufficient oxygen is available to tissues to sustain life and that loss of hemoglobin and Mb expression was not a lethal trait. The second feature is more closely related to the unique evolutionary history of fish fauna in the Southern Ocean that includes a dramatic crash in species diversity that occurred between the mid-Tertiary and present time. This left species of the notothenioid suborder to colonize the entire Southern Ocean and probably has led (perhaps even in the present) to relatively low rates of niche competition compared to most other marine environments. Thus, although decrementing performance, loss of hemoglobin and Mb was not competitively disadvantageous, largely because of very low levels of competition.

If the views articulated above are correct, then even relatively subtle increases in temperature could lead to both significant challenges to the physiology of species that already are compromised by lack of important oxygen-binding proteins and could significantly alter niche competition within the system through incursion of species not normally found in the highest latitudes.

THE PALMER LTER: A LONG-TERM ECOLOGICAL RESEARCH (LTER) PROGRAM IN THE WESTERN ANTARCTIC PENINSULA (WAP) REGION

Raymond C. Smith

Abstract

The Palmer LTER program is a multidisciplinary program established to obtain a comprehensive understanding of the various components of the Antarctic marine ecosystem (Smith et al., 1995; Ross et al., 1996; http://www.icess.ucsb.edu/lter/lter.html). Long-term ecological research addresses the temporal gap between short-term process-oriented and paleo-related studies by focusing on processes with temporal scales from months to decades to centuries. Our study area is located along the western Antarctic Peninsula (WAP) and encompasses the assemblage of plants, animals, ocean, sea ice, and island components comprising this marine ecosystem south of the Antarctic Convergence and north of the Antarctic continent. Along the north-east to south-west trending WAP there are atmospheric, oceanic and sea ice gradients, covering roughly 10° of latitude and 20° of longitude, which impresses a strong influence on the marine ecosystem. These gradients, as well as the relatively large interannual variability within the region, provide an ideal location for "natural" experiments whereby the observed variability is used to study ecological response to variable physical forcing.

To structure our long-term regional observations, we created a sampling grid along the west coast of the Antarctic Peninsula (Waters and Smith, 1992). Establishing a fixed sampling grid was motivated by the need for oceanographic station locations that could be visited repeatedly over time scales of many years. This geographically fixed study area also serves as a basis for a Geographic Information System (Star and Estes, 1990) and serves to simplify seasonal and interannual comparisons as well as facilitate modeling of multidisciplinary data sets. Embedded within the large-scale peninsula grid are smaller sampling grids in the vicinity of Palmer Station. Temporal data are obtained throughout much of the year within the small scale grid as well as from mooring and satellite observations. These fine-scale, mooring and satellite data provide the temporal context within which to embed the less frequent (typically yearly) observations within the large scale grid. An example of the use of this multi-scale sampling strategy for the quantitative estimation pigment biomass and primary productivity is given by Smith and colleagues (American Zoologist, in press). Routine sampling by the Palmer LTER group includes: sea ice, *in situ* bio-optical water properties, temperature, conductivity, dissolved CO_2 concentrations and estimated air-sea fluxes, photosynthetic pigments, nutrient concentrations, phytoplankton and bacterioplankton abundance and production rates, zooplankton abundance and composition, secondary production, particle sedimentation and seabird ecology.

The (WAP) region has experienced a statistically significant warming trend during the past half century (Sansom, 1989; Weatherly et al., 1991; King, 1994; Smith et al., 1996; King & Harangozo, 1998; van den Broeke, 1998; Smith & Stammerjohn, 2001). Also, a statistically significant anti-correlation between air temperatures and sea ice extent, as determined from satellite passive microwave data during the past two decades, has been observed for this region (Jacka, 1990 and above references). Consistent with this strong coupling, sea ice extent in the WAP area has trended down during this period of satellite observations. Further, much of the variability in both air temperature and sea ice in the WAP region has been shown to be influenced by contrasting maritime (warm and moist) and continental (cold and dry) climate regimes. As part of the Palmer Long Term Ecological Research (Palmer LTER) program, the ecological influence of these trends and variability is being studied and effects have already been demonstrated at all trophic levels (see Ross et al., 1996 and references therein). The more recent years have seen an increasing maritime influence in the WAP region, with corresponding effects on the marine ecosystem (Ross et al., 2000).

WORK IN PROGRESS AND LINKAGES WITH WAIS BIOCOMPLEXITY INITIATIVE

Walker Smith

Background

The Ross Sea continental shelf contains significant latitudinal and longitudinal gradients in a number of oceanographic variables. For example, ice concentrations generally are reduced earliest along the Ross Sea ice shelf due to the combined effects of katabatic winds and melting induced by warmer waters advected onto the shelf (Markus, 1999), and hence a N-S gradient exists in ice concentration. Phytoplankton biomass typically is greatest in the south as well (Fig. 12, from Comiso et al.,1993). In general phytoplankton increase earlier in the south, and also reach greater concentrations there; the high biomass southern region is often delineated from the lower biomass waters in the north by an optical front. In addition, east-west gradients in phytoplankton biomass also occur (e.g., Smith et al., 1996; Smith and Gordon, 1997; Arrigo et al., 1999). Superimposed on these gradients is a latitudinal trend in assemblage composition. Waters in the central region are often dominated by the haptophyte *Phaeocystis antarctica*, whereas waters near the coast are dominated by diatoms. Diatoms are also commonly encountered in the eastern zone, and the low-biomass northern sector is a mixed assemblage composed of diatoms, dinoflagellates, flagellated haptophytes, and monads.

These gradients in assemblage composition greatly regulate the associated biogeochemical cycles, such as export from the euphotic zone, mechanisms of vertical flux, rates of micro- and mesozooplankton grazing, and benthic input. Given the strong structuring of the zooplankton community, it would not be unexpected that higher trophic levels also would be influenced by the plankton distributions, with gradients in bird or mammal biomass and foraging success being impacted by planktonic community composition. Hence these gradients potentially could significantly influence the local food web dramatically.

Such north-south gradients are also reflected in the sediments and patterns of vertical flux. For example, organic carbon content (a measure of food availability to benthic organisms) is greatest in the south, and decreases to the north. Longitudinal variations also exist. Biogenic silica concentrations show an even greater gradient, suggesting that diatomaceous input to the sediments has very large N-S gradients. Vertical flux patterns also show a similar gradient, although the magnitude evidenced by the extant data suggest that benthic inputs (vertical flux rates 50 m above the seafloor) is substantially less than those evidence by either surface water variations or benthic patterns.

Present Research

The present focus of my research is to investigate the temporal and spatial patterns of net community production in the southern Ross Sea. This is done using two methods: discrete water column sampling at the end of the growing season, and by continuous measurements of nitrate concentrations from moorings. Two locations are to be used, one dominated by diatoms (north of Ross Island) and one dominated by *Phaeocystis antarctica* (at ca. 178°W). By assessing present variations and linking them with variations calculated from previous cruises to the region (ca. 13 since 1967), it is hoped that the magnitude of interannual variations can be ascertained, as well as its impacts on higher trophic levels.

Vision

I envision linking latitudinal gradients in coastal oceanography (e.g., scales of ca. 100 km from the coast) with the scales of foraging of higher trophic levels during critical periods of their life histories. For example, Adelie penguins may be able to survive during the critical fledgling period on local production (associated with plankton within 50 km of their nests), whereas others such as Emperor penguins may have the ability to use prey that exist over larger scales (greater depth, or greater distances from nests). I would also envision the evaluation of terrestrial inputs (meltwater, iron) on the small scale distribution of phytoplankton (productivity and species composition), and document the latitudinal gradients in these properties, especially as they change through the growing season. Such an approach will elucidate any local "hot spots" of production that play a key role in the support of broader food webs of the coast.

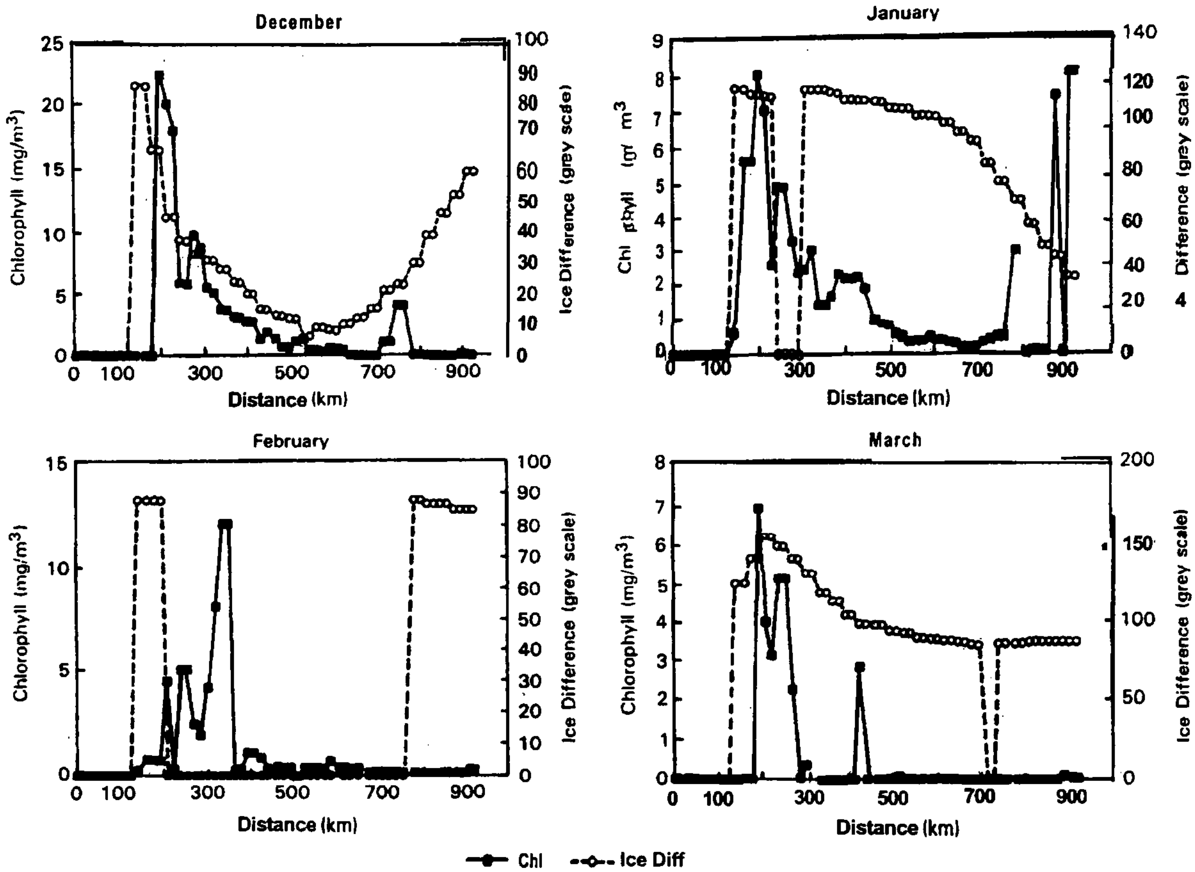


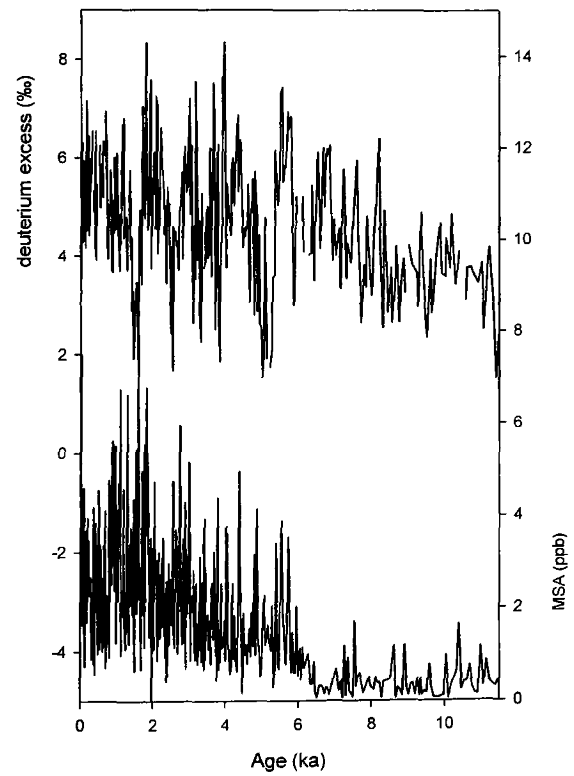
Fig. 12. Plots of pigment concentration and monthly differences in ice concentration along transect A (south to north) for December through March.

THE ICE CORE RECORD OF VICTORIA LAND CLIMATE AND BIOCOMPLEXITY

Eric J. Steig

Ice cores provide an essentially direct record of atmospheric chemistry in the past. Because atmospheric chemistry is controlled by both physical and biological processes, geochemical records from ice cores are a powerful tool for examining the interaction between biology and climate. For example, several ice core studies have linked changes in atmospheric loading of methanesulfonic acid (MSA) to the influence of sea ice on the abundance of algae that produce dimethyldisulfide, the chief MSA precursor. A variety of quantitative information has also been obtained from ice core geochemical data regarding changes in ice sheet air temperature sea surface temperature, wind speed and humidity, and overall atmospheric circulation patterns (e.g. Mayewski *et al.,* 1997, 2001).

Two aspects of recent ice core research deserve particular attention in the context of a Victoria Land transect with a *Biocomplexity* focus. First, comparison of records obtained from various Antarctic sites show that there is considerable spatial heterogeneity. In general, ice cores from the Ross Embayment margin show larger-amplitude geochemical fluctuations than those from most of East Antarctica, including the coastal Law Dome, suggesting a local amplification of climate variability that is probably linked to changes in sea ice cover (Masson *et al.*, 2000). There is also significant spatial heterogeneity in the records even within the Ross Embayment, reflecting the regional nature of storm patterns and the strong influence of orography on transport of chemical species and moisture to the ice sheet. Analysis of spatially comprehensive data from medium-range weather forecast reanalyses, and from satellite remote sensing, demonstrate that the heterogeneity among ice cores reflects real spatial patterns in climate, rather than noise in the records. A clear picture of climate variability in this region therefore requires adequate spatial coverage as well as high temporal resolution. International programs, coordinated under ITASE,* are currently addressing this need through the drilling and analysis of multiple shallow ice cores across the continent. Extending this program along a Victoria Land transect offers great potential for obtaining important locale-specific information. A record of sea salt from a core site chosen strategically, for example, in the catchment area for the Drygalski Ice Tongue, would provide a means to examine past changes in the size and seasonal duration of the Terra Nova Bay polynia.



Concentrations of methanesulfonic acid and deuterium excess at taylor dome. The holocene increase in msa probably reflects increasing productivity of phaeocystis sp.in a thermally stratified water column due to sea ice increases. Increased sea ice in the ross embayment would also lower the contribution of low-deuterium excess, local moisture sources to snowfall at taylor dome. Data from steig et al. (1998) and vimeux et al. (2001) are available at http://depts.washington.edu/isolabsea ice

A second aspect of ice core research that deserves to be highlighted is the development of several innovative analysis techniques that have considerable potential for *Biocomplexity* studies. These include the measurement of sulfur isotopes, which allow discrimination among biogenic, anthropogenic and volcanic sulfate aerosol

*International Trans-Antarctic Scientific Expedition (see http://www.antcrc.utas.edu.au/scar/itase/toc.html).

sources (Kreutz and Sholkovitz, 2000); and of the isotopomers of odd-nitrogen compounds, which are being used to improve our understanding of sources for nitrate deposition (Galanter *et al.*, 2001). Both should significantly enhance our ability to use ice core records to quantify changes in the marine and terrestrial production of these compounds (as opposed to changes in transport efficiency to from source to ice sheet). Also very promising are the measurement in both sulfate and nitrate, as well as in molecular oxygen, of oxygen-17 anomalies (e.g. Galanter *et al.*, 2000; Savarino *et al.*, 2001; Blunier *et al.*, 2001). In O_2, the magnitude of the oxygen-17 anomaly, to first order, is a measure of net terrestrial and marine photosynthesis; the same may also be true for SO_4^{2-} and NO_3, though this is yet to be demonstrated. N and O isotopes offer some promise as a means to reconstruct local UV irradiance levels, because of the distinct wavelengths involved in the photolysis of different odd-N compounds. Finally, improvements in continuous-flow and ICP mass spectrometry are being used to determine concentrations of a variety of organic molecules preserved in ice cores at the ppt level, including organochlorine and organophosphorous compounds that are important ecosystem contaminants (Matthews *et al.*, 2001).

To date, deep ice cores with particular relevance to Victoria Land have been obtained only at Taylor Dome and Newall Glacier at the Southern end of the transect. Shallow cores and snowpit studies have also been obtained at Talos Dome. A program to obtain multiple shallow (~100 m) cores between these sites, parallel with the Victoria Land coast, could provide a comprehensive survey of climate and biogeochemical changes at annual resolution over the last several hundred years with very low logistical impact. Information at decadal to century resolution over the last several millennia could also be obtained with a series of cores to 200-300 meters depths, drilled in dry holes to avoid the logistical burden of using drilling fluid. It would be of particular interest to obtain a late Holocene record at Talos Dome, which should be feasible within that modest logistical framework. An eventual core to bedrock at this site would provide a much-needed complement to the deep cores at Taylor Dome and Dome C, to improve understanding of the long term history of climate and biosphere changes in Victoria Land.

IMPACTS OF CLIMATE ON ECOSYSTEMS: COASTAL UNDERSEA BENTHIC ENVIRONMENTS

Alf Norkko, Simon Thrush, Neil Andrew, Ian Hawes and Anne-Maree Schwarz

We have extended New Zealand's Antarctic Aquatic Ecosystem programme to include research on coastal benthic ecology with the development of "Impacts of Climate on Ecosystems: Coastal Undersea Benthic Environments (ICE CUBE)". This research will add a new dimension to work conducted by Antarctica New Zealand. The work brings together an experienced team of researchers with the relevant skills in primary production and marine benthic population and community ecology. This new component to the programme "Antarctic Aquatic Ecosystems" will increase our understanding of the environmental processes that influence the spatial structure of populations and communities of coastal environments in Antarctica. It is concerned principally with how temporal and spatial changes in sea ice conditions affect primary production and how productivity gradients within and between habitats are functionally linked to the structure and biodiversity of the benthic system. This new project will address how the spatial structure of benthic communities relates to site-specific primary productivity, the role of benthic animals in recycling of pulsed food sources, and the behaviour and resource utilization by mobile benthic species. This work will describe depth- and resource- gradients within locations and, ultimately, between locations along the latitudinal gradient of the Victoria Land coast. In addition, this research forms a basis for the Antarctica New Zealand initiative which proposes to use the latitudinal production gradient in the Ross Sea as a tool for assessing how ecological processes change across productivity gradients and broad spatial scales (*Latitudinal Gradient Project*; LGP, Howard-Williams & Peterson 1999).

The strong seasonality in Antarctic environmental conditions (sea ice cover, light regime) and hence primary production results in a pulsed input of food to benthic communities; this has major ramifications for carbon cycling (Dayton 1990). As a consequence, many benthic invertebrates rely on multiple food sources for survival (i.e., settling pelagic production, settling sea ice algae, benthic diatoms, macroalgal and other detritus and the lateral advection of re-suspended matter; Arntz *et al.* 1994). In the Ross Sea, there is a strong primary production gradient from the Ross Ice Shelf to Cape Adare. But within McMurdo Sound there are also strong east-west gradients in primary production due to oceanographic condictions (Dayton & Oliver 1977, Barry & Dayton 1988, Dayton 1990, Spezie & Manzella 1999). While site-specific studies have provided important information, they do not enable quantitative comparisons among locations subject to different environmental characteristics (Thrush et al. 1997, Andrew & O'Neill 2000). Along this gradient, physico-chemical conditions and coastal marine communities are predicted to respond in a non-linear fashion due to the presence/absence of the Ross Ice Shelf, the extent of the sea ice and coastal polynya.

Given this background we will establish how structure and biodiversity of the benthic system are linked to productivity gradients. We will expand previous work on the relationship between food supply and responses in benthic macrofaunal communities by determining: (i) how temporal (seasonal and inter-annual) and spatial variation in the three major primary production pathways relates to environmental conditions (ii) how the spatial structure of benthic communities relates to site-specific productivity and habitat structure; (iii) the role of benthic animals in the recycling of the pulsed food source (i.e., what are the rates of food uptake); (iv) differences in population structure, growth and the behaviour of key plant and animal species (dominant circumpolar species) in relation to environmental and associated biotic variability ; and in future years, (v) how these questions will be linked to the broad-scale productivity gradient from the Ross Ice Shelf north towards Terra Nova Bay and Cape Adare.

During the first year of this research (2001/02), we will refine sampling techniques and collect baseline data. Research will be initiated in New Harbor and Cape Evans, sites with similar latitudes but markedly different sea ice and oceanographic regimes. Due to prevailing circulation patterns in McMurdo Sound and the proximity to the Ross Ice Shelf, New Harbor experiences very low primary productivity (Dayton et al. 1986) and is characterised by oligotrophic conditions. In contrast, Cape Evans supports abundant sea ice algae during spring, macroalgae populations and a phytoplankton bloom occurs each December/January. In the first phase we will be investigating the processes that determine the productivity of primary producers. Dr McMinn of University of Tasmania is currently measuring sea ice algal production at Cape Evans, and we propose close collaboration with his group. We will extend observations to determine the timing, magnitude and variability of supply of sea-ice diatoms to the sea floor, and contrasting this source of primary production with that derived from macroalgae, phytoplankton and phytobenthos as appropriate. We will describe aspects of the benthic community composition along transects at each site that encompass locally important disturbance and productivity gradients. For key benthic invertebrates such as echinoderms (Brey et al. 1995) and bivalves (Stockton 1984) we will assess the population structure and relative growth rates.

The aim in the initial phase of this research is to develop feasible methods that provide insight into the relationship between spatial pattern and dynamic processes in marine benthic ecosystems to strengthen our capacity to predict the impact of environmental change. This sampling will later be expanded to other sites along the latitudinal gradient. The methods developed in this first phase will be used to sample as many sites as possible within the Ross Sea. By using the same methods and measuring the same suite of variables at each site we will be able to build the study as a series of modules. As the study grows we will add more sites and expand the spatial extent of the analyses in an effort to tease apart the role of processes operating over different spatial scales in influencing the benthic community (Thrush *et al.* 2000). In attempting to describe any regional scale trends in ecological patterns or process we need to understand the magnitude of local variation. Not only can small-scale variation confound the identification of broad scale trends, but also the emergent properties of complex ecological systems can result from the interaction of processes working over different scales. The relative importance of these interactions seems to be more pronounced with increasing diversity and complexity of ecological system. Thus they are likely to be important factors in the Antarctic marine benthic environment, which we will need to understand if we are to ultimately make valid detailed predictions of the ecological consequences of environmental change.

Collaborations and Linkages

This is a new area of research for New Zealand and we are keen to develop strong collaborative links. IRL currently has a major project investigating the physical characteristics of sea ice. This project is currently based at Cape Evans, and in the upcoming year we plan to share facilities and research sites with this group. Interactions between the biological content and the physical properties of ice have recently received considerable attention, and a linkage between these two programmes is likely to have synergistic benefits. By linking with international programmes conducting complementary research in other areas of Antarctica, a continent-wide perspective will be obtained to place this regional study in context. We will link with Australian and British scientists involved with the ECCPANE (Effects of Climate Change on Primary Production of Antarctic Neritic Ecosystems), Ian Hawes been approached by the organizers of this programme to coordinate the Ross Sea contribution to this programme. Other potential collaborators include Professor Paul Dayton (Scripps Institute of Oceanography) who we have worked with previously in Antarctica, and is currently working with us here in New Zealand. As we establish this programme we hope to further extend our national and international research linkages.

CLIMATE, ICE AND BIOLOGICAL CHANGE IN VICTORIA LAND

Edwin D. Waddington

Climate fluctuations in variables such as snowfall, temperature and windiness, drive environmental changes in Antarctica. Changes in biological communities on land can be expected to follow environmental changes such as glacier advance and retreat, and changes in snow cover versus blue ice. Marine biological communities can also change in response to advances of floating glacial ice including ice shelves and glacier ice tongues. Therefore, knowledge of the climate change record obtained from glacier terminus positions and snow line elevations, and from geochemical climate proxies in the polar ice sheet should provide necessary boundary conditions to interpret the temporal changes in biological communities in Victoria Land. In turn, however, records of biological changes over time should help to constrain inferred variations in climate and in glacier and ice shelf positions. For example, radiocarbon dates on algal mats in ice-marginal lakes were used to date the retreat of the Ross ice Sheet from the McMurdo Dry Valleys at the last glaciation (e.g Conway et al., 1999).

In South Victoria Land, paleoclimate information is available from the Taylor Dome ice core record, which covers the past 150 ka (Grootes et al., in press; Steig et al., 2000). In order to determine the climate gradient along the Victoria Land coast over this time period, ice core information from Northern Victoria Land would be extremely valuable, e.g. from Talos Dome. While obtaining long paleoclimate records is expensive and logistically challenging, it should also be possible to obtain a series of millennial records from a range of the small ice caps and glaciers along Victoria Land. Some data exist from Newell Glacier and from the Dominion Range. It may be possible to acquire more cores from the interior side of the Transantarctic Mountains as an extension of the ongoing U.S. ITASE program (P. Mayewski, pers. comm.).

While ice core data provide point measurements of climate with high temporal resolution, glacier geophysical surveys with ice-penetrating radar can reveal spatial patterns in modern and paleo-snowfall. For example, Morse et al. (1998) showed that these data could be used to infer changes in the circulation pattern for moisture bearing storms. At Taylor Dome, the precipitation gradient was reversed at the Last Glacial Maximum and into the Holocene, relative to today. Geophysical surveys of the ice may provide additional clues to past wind and precipitation.

Some biological communities are adapted to live on or near glaciers in the Dry Valleys and on the piedmont glaciers that now block the valley mouths. Glaciological observations such as cryoconite hole conductivity (A. Fountain, pers. comm.) and microwave emissions (D. Winebrenner, pers. comm.) may be adapted to determine the patterns and timing of biological growth on the ice sheet, and meltwater production today. The delivery of meltwater to the terrestrial environment at ice margins is also a biological constraint.

There are potentially a number of valuable interactions between biologists, glaciologists and glacial geologists that could illuminate both how the climate has changed, and how the biome functions along the Victoria Land coast in more detail and with higher certainty than any one scientific community can determine alone.

TERRESTRIAL (SOIL) ECOSYSTEMS

Diana Wall

There is relatively little known and no recent synthesis about the landscape scale distribution of organisms and their relationships to ecosystem functioning (nutrient cycling, decomposition, productivity), habitat (physical and chemical properties), and linkages of soils, freshwater and marine systems in Victoria Land. A preliminary review of the literature suggests that the differences in soil communities vary as much from continental to Ross Island, and from coastal (penquin rookeries) to the Dry Valleys, as we may anticipate within these habitats and across latitudinal gradients. Understanding the factors that limit or determine biotic distribution within and between habitats (freshwater, marine, soil) across these systems and with latitude provides a baseline for understanding potential changes in these ecosystems over time. Biological activities (population size, life history parameters, species diversity) and distribution are some of the parameters used as biotic indicators of global change (land use change, elevated CO2, increased UVB, etc) (Sala et al, 2000, Wall et al., in press, Wolters et al., 2001, Wall et al., in press). The terrestrial biology is influenced by the transport of water, nutrients and organic carbon between landscape units (glaciers, streams, lakes, soils, marine, penquin rookeries). How can these linkages be quantified and examined across latitude over the long term for changes in biology and ecosystem processes?

1. Do legacies of past terrestrial ecosystems define today's contemporary ecosystems across latitudes?

Geological legacies in contemporary temperate ecosystems are not easily apparent because short term changes such as removal of forests and agriculture have modified the soil organic matter (Virginia and Wall, 1999). In all terrestrial ecosystems, soil organic matter provides the most important source of energy for soil food web.

As part of the McMurdo Dry Valley LTER, we have used a concept of past legacies to define our research in soils (http://huey.colorado.edu/LTER/proposal/toc.html). The soil ecosystem in Taylor Valley occupies approximately 95% of the surface area (105km^2), compared to aquatic habitats of lakes (4.7km2) and streams (0.2km2). Legacies of the past in the Dry Valleys, such as pools of soil organic matter deposited by paleo-lakes and nutrients in modern lakes, directly impact present ecosystem function. The patterns of biological activity and diversity reflect past distributions of water, nutrients, organic carbon and biota deposited by paleo lakes. Thus, examination of information on physical and biological processes at small to regional scales, can help to define how past legacies structure today's ecosystems across the Victoria Land Gradient and provide a working concept for uniting landscape units across latitudinal gradients.

a) Linkage of marine to terrestrial soil communities- soil organic carbon

Studies of the natural abundance of carbon (13C/12 C) and nitrogen (15N/14N) isotopes in organic matter from Taylor Valley confirm the existence of multiple sources of carbon in the soils, and show the current importance of legacy of productivity from paleo lakes such as Lake Washburn (Burkins et al. 2000). Transects from near the shores of Lake Hoare (elev. 58m), Fryxell, and Bonney indicate that soil organic carbon sampled at low elevations in the valley is strongly influenced by legacy carbon derived from lacustrine and marine sources. In contrast, soil organic carbon at higher elevation (above 100 m) shows less potential contribution from past lakes and has an isotopic signature consistent with terrestrial production accumulated from the activities of cryptoendolithic microbial communities and soil algae over very long time scales (Burkins et al. 2000). This pattern implies that today's soil food web in the valley may be supported by C fixed long ago. Furthermore, if these sources of organic matter each provide unique substrates for microbial utilization, then sites with multiple sources of organic matter would be expected to have higher microbial biomass and diversity and would support a more complex invertebrate biological community. This indicates that today's soil food web may be supported by carbon fixed long ago, and suggest that for the gradient study, sources and quality of soil organic matter as a base for structuring soil biodiversity would be a potential unifying theme. Secondly, as we have examined $C0^2$ (soil respiration) to understand which systems have biological potential and to isolate the effects of physical controls on potential rates of CO^2 flux, a similar set of measures with the soil organic matter and biodiversity, would be a good integrator for the latitudinal gradient (Parsons et al, in press).

b) Linkage of past lakes to terrestrial soil communities – salinity

Another legacy in Taylor Valley that affects the biotic composition is the spatial distribution of salts deposited during fluctuation levels of paleo lakes (Lyons et al, 1998). Highly saline soils limit development of today's soil communities (Freckman and Virginia 1997, Powers et al., 1998, Wall and Virginia 1999, Courtright et al., in press).

2. What factors explain the distribution of soil biodiversity across the landscape? Do these same factors define the distribution of soil biodiversity across latitudinal gradients?

a. Suitable habitats – soil physical and chemical factors across spatial scales

The terrestrial soil communities in the Dry Valleys are less diverse than other ecosystems and are limited to soil microflora and fauna. Even in the driest soils, without visible vegetation and limited soil moisture, Collembola, mites, nematodes, tardigrades, rotifers, protozoa, fungi and bacteria exist (Bamforth et al., Frati publications, Bargali et al., 1997, Sinclair, in press, Stevens and Hogg, pers comm.). We systematically sampled three valleys and found that moisture is not the primary limiting factor for invertebrate abundance and that salinity and climate better defined suitable habitats and community composition (Courtright et al., in press). Using geographic features (polygons, stream to soil transects, elevational transects) (Powers et al., 1998, Treonis et al. 1999,2000,) as a basis for determining biotic and habitat change across latitudes would contribute to knowledge of linkages, and the prediction of biodiversity under global change scenarios (Wall/Freckman and Virginia 1997, Virginia and Wall 1999, Wall and Virginia, 1999, Burkins et al., 2000, Wall et al., in press).

b. Diversity, taxonomic and genetic – dispersal and spatial scale distribution

Research using molecular tools has shown that Collembola and mites differ considerably from the continent to Ross Island, and with latitude (Frati pubs, Sinclair in press, Stevens and Hogg, pers. comm.). Nematode distribution shows significant DNA variation within local (m^2) and across several valleys (Courtright et al., 2000). Soil protozoa differ from temperate ecosystems in that ciliates decrease in the Ross Island and in the Dry Valleys, and generally occur only in mosses, cyanobacterial mats or penquin guano (Sinclair in press, Bamforth et al., 1993, 1996, pers comm.).

3. Can we identify environmental change in communities across latitudes?

We have used ITEX chambers (International Tundra Experiment) (Marion et al., 1997) to warm the soil and to add carbon, water and mannitol over a six year period to determine how the soil communities are affected by these factors. Using biotic activity (species diversity, population abundance, life history parameters) as an indicator of change, we have noted a decrease in soil moisture and abundance of nematodes. A long term manipulative experiment of this type or snow fences (which increase the duration and availability of water to soil) placed across latitudes will lead to a collaborative understanding of factors determining suitable habitats for biota.

APPENDIX 2

REFERENCES CITED

Acierno, R., C. Agnisola, B. Tota and B.D. Sidell. 1997. Myoglobin enhances cardiac performance in Antarctic icefish species that express the protein. *American Journal of Physiology,* **273**, R100-R106.

Ackley, S.F. 1982. Ice scavenging and nucleation: Two mechanisms for the incorporation of algea into newly forming sea ice. *EOS, Transactions,* American Geophysical Union, **63**, 65.

Ackley, S.F. and C.W. Sullivan. 1994. Physical controls on the development and characteristics of Antarctic sea ice biological communities — a review and synthesis. *Deep Sea Research,* **41**, 1583-1604.

Ackley, S.F. 1986. Sea ice pressure ridge microbial communities. *Antarctic Journal of the United States*, **21**, 172-174.

Ackley, S.F., G.S. Dieckmann and H.T. Shen. 1987. Algal and foram incorporation into new sea ice. *EOS, Transactions,* American Geophysical Union, **68,** 1736.

Aharon, P. 1991. Recorders of reef environment histories: Stable isotopes in corals, giant clams, and calcareous algae. *Coral Reefs,* **10**(2), 71-90.

Ainley, D.G. 1985. Biomass of birds and mammals in the Ross Sea. In: Siegfried, W.R., P.R. Condy and R.M. Laws (eds.), *Antarctic Nutrient Cycles and Food Webs*, Springer-Verlag, Berlin Heidelberg, 498-515.

Ainley, D.G. and R.E. LeResche. 1973. The effects of weather and ice conditions on breeding in Adélie penguins. *Condor,* **75,** 235-255.

Ainley, D.G., E.F. O'Connor and R.J. Boekelheide. 1984. The Marine Ecology of birds in the Ross Sea, Antarctica. *Ornithological Monographs*, **32**, The American Ornithologist Union, 97 pages.

Ainley, D.G., S.S. Jacobs, C.A. Ribic and I. Gaffney. 1998. Seabird distribution and oceanic features of the Amundsen and southern Bellingshausen seas. *Antarctic Science*, **10**(2), 11-123.

Ainley, D.G., P.R. Wilson, K.J. Barton, G. Ballard, N. Nur and B. Karl. 1998. Diet and foraging effort of Adélie penguins in relation to pack-ice conditions in the southern Ross-Sea. *Polar Biology,* **20**, 311-319.

Alverson, K. and F. Oldfield. 1997. PAGES: Past and Future. In: Lunter, S.M. (ed.), *International Geosphere-Biosphere Programme, Global Change Newsletter,* **32**, International Council of Scientific Unions, Stockholm, 2-12.

Andrew, N.L. and A.L. O'Neill. 2000. Large-scale patterns in habitat structure on subtidal rocky reefs in New South Wales. *Marine and Freshwater Research*, **51**, 255-63

Arntz, W.E., T. Brey and V.A. Gallardo. 1994. Antarctic zoobenthos. *Oceanography and Marine Biology Annual Review,* **32**, 241-304.

Arntz, W.E., J. Gutt, and M. Klages. 1997. Antarctic marine biodiversity: an overview. In: Battaglia, B., J. Valencia and D.W.H. Walton (eds.), *Antarctic Communities: Species, Structure and Survival,* Cambridge University Press, Cambridge, 3-14.

Arrigo, K.R., J.N. Kremer and C.W. Sullivan. 1993a. A simulated Antarctic fast ice ecosystem. *Journal of Geophysical Research*, **98**, 6929-6946.

Arrigo, K.R., D.H. Robinson and C.W. Sullivan. 1993b. A high resolution study of the platelet ice ecosystem in McMurdo Sound, Antarctica: Photosynthetic and bio-optical characteristics of a dense microalgal bloom. *Marine Ecology Progress Series*, **98**, 173-185.

Arrigo, K.R. and C.W. Sullivan. 1994. A high resolution bio-optical model of microalgal growth: Tests using sea-ice algal community time-series. *Limnology and Oceanography*, **39**, 609-631.

Arrigo, K.R. and C.R. McClain. 1994. Spring phytoplankton production in the western Ross Sea. *Science*, **266**, 261-263.

Arrigo, K.R. and five others. 1995. High resolution study of the platelet ice ecosystem in McMurdo Sound, Antarctica: Biomass, nutrient and production profiles within a dense microalgal bloom. *Marine Ecology Progress Series*, **127**, 255-268.

Arrigo, K.R., D.L. Worthen, P. Dixon and M.P. Lizotte. 1998a. Primary productivity of near surface communities within Antarctic pack ice. In: Lizotte, M.P. and K.R. Arrigo (eds.), *Antarctic Sea Ice Biological Processes, Interactions and Variability*, *Antarctic Research Series*, **73**, American Geophysical Union, Washington, D.C., 23-43.

Arrigo, K.R., A.M. Weiss and W.O. Smith, Jr. 1998b. Physical forcing of phytoplankton dynamics in the southwestern Ross Sea. *Journal of Geophysical Research*, **103**, 1007-1021.

Arrigo, K. R. and six others. 2000. Phytoplankton taxonomic variability in nutrient utilization and primary production in the Ross Sea. *Journal of Geophysical Research*, **105**, 8827-8846.

Bargagli, R., S. Corsolini, S. Focardi, M.C. Fossi and J.C. Sanchez-Hernandez. 1998. The Antarctic fish *Trematomus bernacchii* as biomonitor of the human activity impact at Terra Nova Bay Station (Ross Sea). *Memoirs of the National Institute of Polar Research*, **52,** 220-230.

Bargagli, R., D. Wynn-Williams, F. Bersan, P. Cavacini, S. Ertz, F. Frati, D. Freckman, R. Lewis-Smith, N. Russell and A. Smith. 1997. Field Report BIOTEX I: First BIOTAS Expedition (Edmonson Point-Baia Terra Nova, Dec 10, 1995 - Feb 6, 1996). In: Tamburrini, M. and R.D'Avino (eds.), *Newsletter for the Italian Biological Research in Antarctica*, Universita degli Studi di Camerino, Gennaio, Italy, 42-58.

Bamforth, S.B., D.W. Freckman and R.A. Virginia. 1993. Soil Protozoa of the Dry Valleys of Antarctica. *IX International Congress of Protozoology*, Berlin.

Bamforth, S.B., D.W. Freckman and R.A.Virginia. 1996. Amoebae biodiversity in the Antarctic Dry Valley soils. *7th International Conference on Small, Freeliving Amoebae*, Adelaide, January.

Baroni, C. and G. Orombelli. 1991. Holocene raised beaches at Terra Nova Bay, Victoria Land, Antarctica. *Quaternary Research,* **36**, 157-177.

Baroni, C. and G. Orombelli. 1994. Abandoned penguin colonies as Holocene paleoclimatic indicators in Antarctica. *Geology,* **22**, 23-26.

Baroni, C. and G. Orombelli. 1994. Holocene glacier variations in the Terra Nova Bay area (Victoria Land, Antarctica). *Antarctic Science*, **6**, 497-505.

Barry, J.P. and P.K. Dayton. 1988. Current patterns in McMurdo Sound, Antarctica and their relationship to local biotic communities. *Polar Biology*, **8**(5), 367-376.

Barry, J.P. and P.K. Dayton. 1988. Current patterns in McMurdo Sound, Antarctica and their relationship to biological production of local benthic communities. *Polar Biology*, **8**, 377-391.

Bemis, B.E. and D.H. Geary. 1996. The usefulness of bivalve stable isotope profiles as environmental indicators: Data from the eastern Pacific Ocean and the southern Caribbean Sea. *Palaios*, **11**(4), 328-339.

Benninghoff, W.S. and W.N. Bonner. 1985. *Man's Impact on the Antarctic Environment.* Scientific Committee on Antarctic Research, Cambridge.

Berger, G.W. and P.T. Doran. In press. Luminescence zeroing tests in Lake Hoare, Taylor Valley, Antarctica. *Journal of Paleolimnology.*

Berkman, P.A. 1992a. The Antarctic marine ecosystem and humankind. *Review of Aquatic Science,* **6**, 295-333.

Berkman, P.A. 1992b. Circumpolar distribution of Holocene marine fossils in Antarctic beaches. *Quaternary Research,* **37**, 256-260.

Berkman, P.A. 1997. Ecological variability in Antarctic coastal environments: past and present. In: Battaglia, B., J. Valencia, and D.W.H. Walton (eds.), *Antarctic Communities: Species, Structure and Survival*, London, Cambridge University Press, 349-357.

Berkman, P.A. 2002. *Science into Policy: Global Lessons from Antarctica.* Academic Press, San Diego.

Berkman, P.A. and M. Nigro. 1992. Trace metal concentrations in scallops around Antarctica: Extending the Mussel Watch Programme to the Southern Ocean. *Marine Pollution Bulletin*, **24**(124), 322-323.

Berkman, P.A., J.T. Andrews, S. Björck, E.A. Colhoun, S.D. Emslie, I. Goodwin, B.L. Hall, C.P. Hart, K. Hirakawa, A. Igarashi, O. Ingólfsson, J. López-Martínez, W.B. Lyons, M.C.G. Mabin, P.G. Quilty, M. Taviani and Y. Yoshida. 1998. Circum-Antarctic coastal environmental variability during the Late Quaternary recorded in emerged marine deposits. *Antarctic Science,* **10**(3), 345-362.

Block, W. 1984. Terrestrial microbiology, invertebrates and ecosystems. In: Laws, R.M. (ed.), *Antarctic Ecology,* **1,** Academic Press, New York, 163-236.

Blunier, T., M.L. Bender and M.B. Hendricks. 2001. Biological oxygen productivity over the last glacial termination from triple oxygen isotope measurements. *Abstract Volume, Spring 2001 Meeting of the American Geophysical Union, Session OS51B, Ice Cores Paleoclimates, Glaciology, and Environmental Change.*

Blunier, T., J. Chappellaz, J. Schwander, B. Stauffer and D. Raynaud. 1995. Variations in atmospheric methane concentration during the Holocene epoch. *Nature,* **374**, 46-49.

Bockheim, J.G., S.C. Wilson, G.H. Denton, B.G. Andersen and M. Stuiver. 1989. Late Quaternary ice-surface fluctuations of Hatherton Glacier, Transantarctic Mountains. *Quaternary Research,* **31**, 229-254.

Bockus, D. 1999. *Anchor Ice Disturbance in McMurdo Sound, Antarctica and The Structure of Benthic Infaunal Communities.* MS Thesis, California State University-Stanislaus/Moss Landing Marine Labs, 54 pages.

Brasier, M., O. Green and G. Shields. 1997. Ediacarian sponge spicule clusters from southwestern Mongolia and the origins of the Cambrian fauna. *Geology*, **25**(4), 303-306.

Brey, T., J. Pearse, L. Basch, J. McClintock and M. Slattery. 1995. Growth and production of *Sterechinus neumayeri* (echinoidea;echinodermata) in McMurdo Sound, Antarctica. *Marine Biology,* **124**, 279-292.

Broady, P.A. 1993. Soils heated by volcanism. In: Friedman, E.I. (ed.), *Antarctic Microbiology*, Wiley-Liss Inc., New York, NY, 413-433.

Broady, P.A. and R.N. Weinstein. 1998. Algae, lichens and fungi in La Gorce Mountains, Antarctica. *Antarctic Science,* **10**, 376-385.

Bromwich, D.H. 1991. Mesoscale cyclogenesis over the Southwestern Ross Sea linked to strong katabatic winds. *Monthly Weather Review*, **119,** 1736-1752.

Bromwich, D.H. 1992. A case study of a katabatic surge along the Transantarctic Mountains, *International Journal of Remote Sensing*, **13**(1), 55-66.

Bromwich, D.H. and D.D. Kurtz. 1984. Katabatic wind forcing of the Terra Nova Bay polynya, *Journal of Geophysical Research,* **89**, 3561-3572.

Bromwich, D.H. and C.R. Stearns (eds.). 1994. *Antarctic Meteorology and Climatology: Studies Based on Automatic Weather Stations, Antarctic Research Series,* **61**, American Geophysical Union, Washington, D.C., 207 pages.

Bromwich, D.H., Y. Du and T.R. Parish. 1994. Numerical simulation of winter katabatic winds from West Antarctica crossing Siple Coast and the Ross Ice Shelf. *Monthly Weather Review*, **122**, 1417-1435.

Bromwich, D.H., Z. Liu, A.N. Rogers and M.L. Van Woert. 1998. Winter atmospheric forcing of the Ross Sea polynya. In: Jacobs, S.S. and R.F. Weiss (eds.), *Ocean, Ice and Atmosphere: Interactions at the Antarctic Continental Margin, Antarctic Research Series*, **75**, American Geophysical Union, Washington, D.C., 101-133.

Bunt, J.S. 1964. Primary productivity under sea ice in Antarctic waters. I. Concentrations and photosynthetic activities of microalgae in the waters of McMurdo Sound. In: Lee, M.O. (ed.), *Biology of the Antarctic Seas*, *Antarctic Research Series*, **1**, American Geophysical Union, Washington, D.C., 13-26.

Burkins, M.B., R.A. Virginia and D.H. Wall. 2001. Organic Carbon Cycling in Taylor Valley, Antarctica: Quantifying Soil Reservoirs and Soil Respiration. *Global Change Biology,* **7**, 113-125.

Burkins, M.B., R.A. Virginia, C.P. Chamberlain and D.H. Wall. 2000. Origin and distribution of soil organic matter in Taylor Valley, Antarctica. *Ecology,* **81**, 2377-2391.

Campbell, J.B. 1996. *Introduction to Remote Sensing*, 2nd Edition. The Guilford Press, New York, 621 pages.

Carrasco, J.F. and D.H. Bromwich. 1996. Mesoscale cyclone activity near Terra Nova Bay and Byrd Glacier, Antarctica during 1991. *Global Atmospheric Ocean Systems*, **5**, 43-72.

Cashon, R.E., M.E. Vayda and B.D. Sidell. 997. Kinetic characterization of myoglobins from vertebrates with vastly different body temperatures. *Comparative Biochemical Physiology,* **117B**, 613-620.

Cassano, J.J., J.E. Box, D.H. Bromwich, L. Li and K. Steffen. In press. Verification of Polar MM5 Simulations of Greenland's Atmospheric Circulation. *Journal of Geophysical Research, Special Issue on the PARCA (Program for Arctic Regional Climate Assessment) Program*, accepted pending revisions.

Chen, L., A.L. DeVries and C.C. Cheng. 1997. Evolution of antifreeze glycoprotein gene from a trypsinogen gene in Antarctic notothenioid fish. *Proceedings of the National Academy of Science of the USA*, **94**, 3811-3816.

Cherel, Y. and G.L. Kooyman. 1998. Food of emperor penguins (*Aptenodytes forsteri*) in the western Ross Sea, Antarctica. *Marine Biology* (Berlin), **130,** 335-344.

Chernova, N.V. and J.T. Eastman. 2001. Two new species of snailfish genus *Paraliparis* (Pisces: Liparidae) from the Ross Sea, Antarctica. *Journal of Fish Biology*, **59**, in press.

Chiantore, M., R. Cattaneo-Vietti, P. Berkman, M. Nigro, M. Vacchi, S. Schiaparelli, M. Guidetti and G. Albertelli. 2000. Antarctic scallop (Adamussium colbecki) spatial and temporal population variability along the Victoria Land Coast, Antarctica. *Polar Biology*, **24**, 139-143.

Chinn, T.J.H. 1980. Glacier balances in the Dry Valleys area, Victoria Land, Antarctica. *IAHS Publication,* **126**, 237-247.

Chinn, T.J.H. 1986. Hydrology and climate in the Ross Sea area. *Journal of the Royal Society of New Zealand*, **11**(4), 373-386.

Chinn, T.J. 1993. Physical hydrology of the Dry Valley Lakes. In: Greene, W.J. and E.I. Friedman (eds.), *Physical and Biogeochemical Processes in Antarctic Lakes, Antarctic Research Series,* **59**, American Geophysical Union, Washington, D.C., 1-51.

Chrisman, N. 1997. *Exploring Geographic Information Systems.* John Wiley and Sons, Inc., New York, 298 pages.

Clarke, A. 1996. Benthic marine habitats in Antarctica. In: Ross, R.M, E.E. Hofmann and L.B. Quetin (eds.), *Foundations for Ecological Research West of the Antarctic Peninsula, Antarctic Research Series,* **70,** American Geophysical Union, Washington, D.C., 123-133.

Clarke, A. and J.A. Crame. 1989. The origin of the Southern Ocean marine fauna. In: Crame, A.J. (ed.), *Origins and Evolution of the Antarctic Biota, GSA Special Publication,* **47**, 253-268.

Clarke, A., J.A. Crame, et al. 1992. Southern ocean benthic fauna and climate change: a historical perspective. *Royal Society of London, Philosophical Transactions Series B,* **338**(1285), 299-309.

Colacino, M., E. Piervitali and Grigioni. 2000. Climatic characterization of the Terra Nova Bay region. In: Faranda, F.M., L. Guglielmo and A. Ianora (eds.), *Ross Sea Ecology: Italianantartide Expeditions (1987-1995)*, Springer, Milan, 15-26.

Conlan, K.E., H.S. Lenihan, R.G. Kvitek and J.S. Oliver. 1998. Ice scour disturbance to benthic communities in the Canadian high arctic. *Marine Ecology Progress Series*, **166**, 1-16.

Conway, H., B.L. Hall, G.H. Denton, A.M. Gades and E.D. Waddington. 1999. Past and future grounding-line retreat of the West Antarctic Ice Sheet. *Science*, **286**(5438), 280-283.

Corsolini, S., M. Nigro, S. Olmastroni, S. Focardi and F. Regoli. 2001. Susceptibility to oxidative stress in Adélie and Emperor penguin. *Polar Biology*, **24**, 365-368.

Corsolini S., S. Focardi, S. Aurigi and E. Barrera-Oro. 1998. Polychlorinated biphenyl pollution and toxicity in Antarctic marine organisms. *New Zealand Natural Science,* **23(suppl.),** 40.

Corsolini S., K. Kannan, T. Evans, S. Focardi and J.P. Giesy. 2000. Polychlorinated biphenyls in Arctic and Antarctic organisms: polar bear, krill, fish, Weddell seal and skua. *Organohalogen Compounds*, **46**, 314-317.

Costa, D.P. 1993. The secret life of marine mammals: Novel tools for studying their behavior and biology at sea. *Oceanography*, **6**:120-128.

Courtright, E., D. Wall and R.A. Virgina. In press. Determining habitat suitability for soil invertebrates in an extreme environment: The McMurdo Dry Valleys, Antarctica. *Antarctic Science.*

Courtright, E.M., D.H. Wall, R.A. Virginia, L.M. Frisse, J.T. Vida and W.K. Thomas. 2000. Nuclear and Mitochondrial DNA Sequence Diversity in the Antarctic Nematode *Scottnema lindsayae*. *Journal of Nematology*, **32**, 143-153.

Crocker, G.B. and P. Wadhams. 1989. Modelling of Antarctic fast-ice growth. *Journal of Glaciology*, **35**, 3-8.

Croll, D.A., B.R. Tershy, R.P. Hewitt, D.A. Demer, P.C. Fiedler, S.E. Smith, W. Armstrong, P. J.M., T. Kiekhefer, V.R. Lopez, J. Urban and D. Gendron. 1998. An integrated approach to the foraging ecology of marine birds and mammals. *Deep-Sea Research. Part II*, **45**(7), 1353-1371.

Croxall, J.P., W.K. Steele, S.J. McInnes and P.A. Prince. 1995. Breeding distribution of the Snow Petrel *Pagodroma nivea* . *Marine Ornithology*, **23**(2), 69-99.

Cunningham, W.L. 1997. *The Use of Modern and Fossil Diatom Assemblages as Climate Proxies in the Central and Western Ross Sea, Antarctica.* Masters Thesis, University of Colorado, Boulder.

Cunningham, W.L. and A. Leventer. 1998. Diatom assemblages in surface sediments of the Ross Sea: Relationship to present oceanographic conditions. *Antarctic Science*, **10**, 134-146.

Cunningham, W.L., A. Leventer, J.T. Andrews, A.E. Jennings and K.J. Licht. 1999. Late Pleistocene-Holocene marine conditions in the Ross Sea, Antarctica: evidence from the diatom record. *The Holocene*, **9**, 129-139.

Darby, M.S., A.J. Willmott and T.A. Somerville. 1995. On the influence of coastline orientation on the steady state width of a latent heat polynya. *Journal of Geophysical Research*, **100**, 13,625-13,633.

Dawber, M. and R.D. Powell. 1998. Epifaunal distributions at marine-ending glaciers: influences of ice dynamics and sedimentation. In: Ricci, C.A. (ed.), *The Antarctic Region: Geological Evolution and Processes, Proceedings of the VII International Symposium on Antarctic Earth Sciences, Siena, Italy, 1995,* Terra Antartica, Siena, 875-884.

Dayton, P.K. 1989. Interdecadal variation in an antarctic sponge and its predators from oceanographic climate shifts. *Science*, **245**(4925), 1484-1486.

Dayton, P.K. 1990. Polar benthos. In: Smith, W.O. (ed.), *Polar Oceanography*, *Part B*: *Chemistry, Biology,* and *Geology*, Academic Press, London, 631-685.

Dayton, P.K. and J.S. Oliver. 1977. Antarctic soft-bottom benthos in oligotrophic and eutrophic environments. *Science*, **197**(4435), 55-58.

Dayton, P.K., J.S. Oliver, et al. 1978. Long-term experimental benthic studies in McMurdo Sound. *Antarctic Journal of the United States,* **13**(4), 136-137.

Dayton, P.K., G.A. Robilliard and A.L. DeVries. 1969. Anchor ice formation in McMurdo Sound, Antarctica and its biological effects. *Science*, **163**, 273-274.

Dayton, P.K., et al. 1974. Biological accommodation in the benthic community at McMurdo sound, Antarctica. *Ecological Monographs*, **44**, 105-128.

Dayton, P.K., D. Watson, A. Palmisano, J.P. Barry, J.S. Oliver and D. Rivera. 1986. Distribution patterns of benthic microalgal standing stock at McMurdo Sound, Antarctica. *Polar Biology*, **6**, 207-213.

DeMaster, D.J., O. Ragueneau and C.A. Nittrouer. 1996. Preservation efficiencies and accumulation rates for biogenic silica and organic C, N, and P in high-latitude sediments: The Ross Sea. *Journal of Geophysical Research*, **101**(C8), 18,501-18,518.

DeMers, M.N. 2000. *Fundamentals of Geographic Information Systems*, 2nd Edition. John Wiley and Sons, Inc., New York, 498 pages.

Denton, G.H., J.G. Bockheim, S.C. Wilson and M. Stuiver. 1989. Late Wisconsin and Early Holocene Glacial History, Inner Ross Embayment, Antarctica. *Quaternary Research*, **31**, 151-182.

Dieckmann, G.S., G. Rohardt, H.H. Hellmer and J. Kipfstuhl. 1986. The occurrence of ice platelets at 250 m depth near the Filchner Ice Shelf and its significance for sea ice biology. *Deep Sea Research*, **33**, 141-148.

DiTullio, G.R. and eight others. 2000, Rapid and early export of *Phaeocystis antarctica* blooms in the Ross Sea, Antarctica. *Nature*, **404**, 595-598.

Domack, E.W. and P.A. Mayewski. 1999. Bi-polar ocean linkages: evidence from late Holocene Antarctic marine and Greenland ice-core records. *The Holocene*, **9**, 247-251.

Domack, E.W., E.A. Jacobson, S. Shipp and J.B. Anderson. 1999. Late Pleistocene-Holocene retreat of the West Antarctic Ice-Sheet system in the Ross Sea: Part 2 – Sedimentologic and stratigraphic signature. *Geological Society of America Bulletin*, **111**,1517-1536.

Domack, E., A. Leventer, R. Dunbar, F. Taylor, S. Brachfeld, C. Sjunneskog and ODP Leg 178 Scientific Party. 2001. Chronology of the Palmer Deep site, Antarctic Peninsula: a Holocene palaeoenvironmental reference for the circum-Antarctic. *The Holocene*, **11**, 1-9.

Doran, P.T., C.P. McKay, M.A. Meyer, D.T. Andersen, R.A. Wharton and J.T. Hastings. 1996. Climatology and implications for perennial lake ice occurrence at Bunger Hills Oasis, East Antarctica. *Antarctic Science*, **8**(3), 289-296.

Doran, P.T., G. Berger, R.A. Wharton Jr., W.B. Lyons, L. Davisson, J. Southon and J. Dibb. 1999. Dating Quaternary lacustrine sediments in the McMurdo Dry Valleys Antarctica. *Palaeography, Palaeoclimatology, Palaeoecology*, **147**, 223-239.

Doran, P.T., G. Dana, J.T. Hastings and R.A. Wharton. 1995. The McMurdo LTER Automatic Weather Network (LAWN). *Antarctic Journal of the United States,* **30**(5), 276-280.

Doran, P.T., R.A. Wharton, Jr. and W.B. Lyons. 1994. Paleolimnology of the McMurdo Dry Valleys, Antarctica. *Journal of Paleolimnology*, **10**(2), 85-114.

Doran, P.T., R.A. Wharton Jr., D. DesMarais, and C.P. McKay. 1998. Antarctic paleolake sediments and the search for extinct life on Mars. *Journal of Geophysical Research – Planets*, **103**(E12), 28481-28493

Doran, P.T., R.A. Wharton Jr., S. Spaulding and J. Foster. 1994. McMurdo LTER: Paleolimnology of Taylor Valley. *Antarctic Journal of the United States*, **24**(5), 234-237.

Doran, P.T., R.A. Wharton, W.B. Lyons, D.J. DesMarais and D.T. Andersen. 2000. Sedimentology and Geochemistry of a Perennially Ice-Covered Epishelf Lake in Bunger Hills Oasis, East Antarctica. *Antarctic Science,* **12**(2), 131-140.

Downes, M.T., C. Howard-Williams, I. Hawes and A-M. Schwarz. 2000. Nitrogen dynamics in a tidal lagoon at Bratina Island, McMurdo Ice Shelf, Antarctica. In: Davison W. et al (eds.), *Antarctic Ecosystems: Models for Wider Ecological Understanding*, New Zealand Natural Sciences, Canterbury University, Christchurch, 19-25.

Drewry, D.J. (ed.). 1983. *Glaciological and Geophysical Folio. Sheet 2.* Scott Polar Research Institute, Cambridge.

Dueker, K.J. and D. Kjerne. 1989. *Multi-Purpose Cadastre: Terms and Definitions*. ASPRS and ACSM, Falls Church, Virginia.

Dunbar, R.B., J.B. Anderson, E.W. Domack and S.S. Jacobs. 1985. Oceanographic influences on sedimentation along the Antarctic continental shelf. In: Jacobs, S.S. (ed.), *Oceanology of the Antarctic Continental Shelf, Antarctic Research Series*, **43**, American Geophysical Union, Washington D.C., 291-312.

Dunbar, R.B., A. Leventer, et al. 1991. Circulation in eastern McMurdo Sound, Antarctica, January through November 1990. *Antarctic Journal of the United States*, **27**(5), 117-120.

Eastman, J.T. and R.R. Eakin. 2000. An updated species list for notothenioid fish (*Perciformes; Notothenioidei*), with comments on Antarctic species. *Archive of Fishery and Marine Research*, **48,** 11-20.

Eastman, J.T. and G. Hubold. 1999. The fish fauna of the Ross Sea, Antarctica. *Antarctic Science*, **11,** 293-304.

Eastman, J.T. and A.R. McCune. 2000. Fishes on the Antarctic continental shelf: evolution of a marine species flock? *Journal of Fish Biology*, **57** (Supplement A), 84-102.

Eicken, H. and M.A. Lange. 1989. Development and properties of sea ice in the coastal regime of the southeastern Weddell Sea. *Journal of Geophysical Research*, **94**, 8193-8206.

Emery, A.R. 1978. The basis of fish community structure: marine and freshwater comparisons. *Environmental Biology of Fishes*, **3**, 33-47.

Emslie, S.D., W. Fraser, R.C. Smith and W. Walker. 1998. Abandoned penguin colonies and environmental change in the Palmer Station area, Anvers Island, Antarctic Peninsula. *Antarctic Science*, **10,** 257-268.

Ensor, P.H. 1979. The effect of storms on the breeding success of south polar skuas at Cape Bird, Antarctica. *Notornis*, **26**, 349-352.

Faranda, F.M., L. Guglielmo and A. Ianora (eds.). 2000. *Ross Sea Ecology: Italiantarde Expeditions (1987-1995)*, Springer, Berlin, New York, 604 pages.

Fichefet, T. and H. Goosse. 1999. A numerical investigation of the spring Ross Sea polynya. *Geophysical Research Letters*, **26**, 1015-1018.

Fields, P.A. and G.N. Somero. 1998. Hot spots in cold adaptation: Localized increases in conformational flexibility of lactate dehydrogenase A_4 orthologs of Antarctic notothenioid fishes. *Proceedings of the National Academy of Science, U.S.A.*, **95**, 11476-11481.

Focardi, S, S. Corsolini and R. Bargagli. 1995. Isomer-specific analysis and toxic evaluation of polychlorinated biphenyls in Antarctic fish, seabirds and Weddell seal from Terra Nova Bay (Ross Sea). *Antarctic Science*, **7**, 31-35

Focardi, S., R. Bargagli and S. Corsolini. 1993. Organochlorines in marine Antarctic food chain at Terranova Bay (Ross Sea). *Korean Journal of Polar Research*, **4**, 73-77.

Focardi, S, M.C. Fossi, L. Lari, S. Casini, C. Leonzio, S.K. Meidel and M. Nigro. 1995. Induction of MFO Activity in the antarctic fish *Pagothenia bernacchi*: Preliminary results. *Marine Environmental Research,* **39**, 97-100.

Fountain, A.G., K.J. Lewis and P.T. Doran. 1999. Spatial and climatic variations and its control on glacier equilibrium line altitude in Taylor Valley, Antarctica. *Global and Planetary Change*, **22**(1), 1-10.

Fountain, A.G., W.B. Lyons, M.B. Burkins, G.L. Dana, P.T. Doran, K.J. Lewis, D.M. McKnight, D.L. Moorhead, A.N. Parsons, J.C. Priscu, D.H. Wall, R.A. Wharton, Jr and R.A. Virginia. 1999. Physical controls on the Taylor Valley ecosystem, Antarctica. *Bioscience*, **49**, 961-971.

Fraser, W.R., W.Z. Trivelpiece, D.G. Ainley and S.G. Trivelpiece. 1992. Increases in Antarctic penguin populations - reduced competition with whales or a loss of sea ice due to environmental warming. *Polar Biology*, **11**, 525-531.

Frati, F. 1999. Distribution and ecophysiology of terrestrial microarthropods in the Victoria Land. *Newsletter of the Italian Biological Research in Antarctica*, **3**, 13-19.

Frati, F. and E. Dell'Ampio. 2000. Molecular phylogeny of three subfamilies of the Neanuridae (Insecta, Collembola) and the position of the antarctic species Friesea grisea Schaffer. *Pedobiologia*, **44**(3-4), 342-360.

Frati, F., P.P. Fanciulli, et al. 1997. The Collembola of northern Victoria Land (Antarctica): distribution and ecological remarks. *Pedobiologia*, **41**, 50-55.

Frati, F., P.P. Fanciulli, et al. 2000. DNA sequence analysis to study the evolution of Antarctic Collembola. *Italian Journal of Zoology*, **67**(Suppl.), 133-139.

Fritsen, C.H., S.F. Ackley, J.N. Kremer and C.W. Sullivan. 1998. Flood-freeze cycles and microalgal dynamics in Antarctic pack ice. In: Lizotte, M.P. and K.R. Arrigo (eds.), *Antarctic Sea Ice Biological Processes, Interactions and Variability*, *Antarctic Research Series*, **73**, American Geophysical Union, Washington, D.C., 1-21.

Fritsen, C.H., J.N. Kremer, S.F. Ackley and C.W. Sullivan. 1998. Flood-freeze cycles and algal dynamics in Antarctic pack ice. In: Lizotte, M.L. and K.R. Arrigo (eds.), *Antarctic Sea Ice: Biological Processes, Antarctic Research Series*, **73**, American Geophysical Union, 1-21.

Fritsen, C.H., V.I. Lytle, S.F. Ackley and C.W. Sullivan. 1994. Autumn bloom of Antarctic pack ice algae. *Science*, **266**, 782-784.

Fritsen, C.H. and C.W. Sullivan. 1997. Distributions and dynamics of microbial communities in the pack ice of the western Weddell Sea, Antarctica. In: Battaglia, B., J. Valencia and D.W.H. Walton (eds.), *Antarctic Communities: Species, Structure and Survival*, London, Cambridge University Press, 101-106.

Galanter, M., D.M. Sigman, H. Levy, J.K. Bohlke, E.J. Lipschultz and E.J. Steig. 2000. Controls on the oxygen isotopic composition of atmospheric derived nitrate. *EOS, Transactions*, **81**, 191.

Galanter, M., E.J. Steig and D.M. Sigman. 2001. N and O Isotopes of nitrate in the GISP2 ice core: implications for the interpretation of ice-core nitrate profiles. *Abstract Volume, Spring 2001 Meeting of the American Geophysical Union, Session OS51B, Ice Cores Paleoclimates, Glaciology, and Environmental Change.*

Gallée, H. 1997. Air-sea interactions over Terra Nova Bay during winter: Simulation with a coupled atmosphere-polynya model. *Journal of Geophysical Research*, **102**, 13,835-13,849.

Garrison, D.L., S. F. Ackley and K.R. Buck. 1983. A physical mechanism for establishing algal populations in frazil ice. *Nature*, **306**, 363-365.

Garrison, D.L., C.W. Sullivan and S.F. Ackley. 1986. Sea ice microbial communities in Antarctica. *BioScience*, **36**(4), 243-250.

Gilmour, A.E., W.J.P. Macdonald and F.G. Van der Hoeven. 1960. Ocean currents in McMurdo Sound. *Nature*, **187**(4740), 867.

Giovinetto, M.B. and C.R. Bentley. 1985. Surface balance in ice drainage systems of Antarctica. *Antarctic Journal of the United States,* **20**, (4), 6-15.

Gordon, A.L. and J.C. Comiso. 1988. Polynyas in the southern ocean. *Scientific American,* **258**(6), 90-97.

Gow, A.J., S.F. Ackley, W.F. Weeks and J.W. Govoni. 1982. Physical and structural characteristics of Antarctic sea ice. *Annals of Glaciology*, **3**, 113-117.

Gow, A.J., S.F. Ackley, J.W. Govoni and W.F. Weeks. 1998. Physical and structural properties of landfast sea ice in McMurdo Sound, Antarctica. In: Jeffries, M.O. (ed.), *Antarctic Sea Ice: Physical Processes, Interactions and Variability*, *Antarctic Research Series*, **74**, American Geophysical Union, Washington, D.C., 69-88.

Greene, W.J. and E.I. Friedman (eds.). 1993. *Physical and Biogeochemical Processes in Antarctic Lakes, Antarctic Research Series,* **59,** American Geophysical Union, Washington, D.C.

Grootes, P.M., E.J. Steig, M. Stuiver, E.D. Waddington and D.L. Morse. In press. New long Taylor Dome Antarctic ^{18}O record indicates synchroneity of global glacial climate fluctuations. *Quaternary Research.*

Grossi, S.M., S.T. Kottmeier, R.L. Moe, G.T. Taylor and C.W. Sullivan. 1987. Sea ice microbial communities. IV. Growth and production of bottom ice under graded snow cover. *Marine Ecology Progress Series*, **35**, 153-164.

Grossi, S.M., S.T. Kottmeier and C.W. Sullivan. 1984. Sea ice microbial communities. III. Seasonal abundance of microalgae and associated bacteria, McMurdo Sound, Antarctica. *Microbial Ecology,* **10**, 231-242.

Guglielmo, L., G.C. Carrada, G. Catalano, A. Dell'Anno, M. Fabiano, L. Lazzara, O. Mangoni, A. Pusceddu and V. Saggiomo. 2000. Structural and functional properties of sympagic communities in the annual sea ice at Terra Nova Bay (Ross Sea, Antarctica). *Polar Biology,* **23**, 137-146.

Hall, B.L., G.H. Denton, D.R. Lux and J.G. Bockheim. 1993. Late Tertiary Antarctic peleoclimate and ice-sheet dynamics inferred from surficial deposits in Wright Valley. *Geografiska Annaler,* **75A**(4), 239-267.

Hall, B.L. and G.H. Denton. 1999. New relative sea-level curves for the southern Scott Coast, Antarctica: evidence for Holocene deglaciation of the western Ross Sea. *Journal of Quaternary Science*, **14**(7), 641-650.

Hall, B.L. and G.H. Denton. 2000. Extent and chronology of the Ross Sea Ice Sheet and the Wilson Piedmont Glacier along the Scott Coast at and since the last glacial maximum. *Geografiska Annaler,* **82A**(2-3), 337-363.

Harris, P.T. 2001. Ripple cross-laminated sediments on the East Antarctic Shelf: evidence for episodic bottom water production during the Holocene. *Marine Geology*, **170**, 317-330.

Harris, P.T., E.W. Domack, P.L. Manley, R. Gilbert and A. Leventer. 1999. Andvord drift: a new type of glacial marine deposystem from the coastal regime of the Antarctic Peninsula. *Geology*, **27**, 683-686.

Hastings, J.T. 1998. Digital geospatial datasets pertaining to the McMurdo Dry Valleys of Antarctica: the SOLA/AGU CDROM. In: Priscu, J. (ed.), *Ecosystem Dynamics in a Polar Desert: the McMurdo Dry Valleys, Antarctica, Antarctic Research Series,* **72,** American Geophysical Union, Washington, D.C., 365-369.

Hawes, I., C. Howard-Williams and R.D. Pridmore. 1993. Environmental control on microbial communities in the ponds of the McMurdo Ice Shelf, Antarctica. *Archiv fur Hydrobiologie*, **127**, 271-287.

Hawes, I., C. Howard-Williams, A-M. Schwarz and M.T. Downes. 1997. Environment and microbial communities in a tidal lagoon at Bratina Island, McMurdo Ice Shelf, Antarctica. In: Battaglia, B., J. Valencia and D.W.H. Walton (eds.), *Antarctic Communities: Species, Structure and Survival*, London, Cambridge University Press, 170-177.

Hines, K.M., D.H. Bromwich and T.R. Parish. 1995. Mesoscale modelling study of the atmospheric circulation of high southern latitudes. *Monthly Weather Review*, **123**, 1146-1165.

Hines, K.M., D.H. Bromwich and Z. Liu. 1997. Combined global climate model and mesoscale model simulations of Antarctic climate. *Journal Geophysical Research*, **102**, 13,747-13,760.

Hines, K.M., D.H. Bromwich and L. Zhang. In review. August teleconnections of the southern hemisphere high and middle latitudes to the tropical intraseasonal oscillation and the East Asian Monsoon. *Journal of Climate*.

Holligan, P.M. and W.A. Reiners. 1992. Predicting the responses of the coastal zone to global change. *Advances in Ecology Research,* **22**, 211-255.

Howard-Williams, C., R.D. Pridmore, M.T. Downes and W.F. Vincent. 1989. Microbial biomass, photosynthesis and chlorophyll *a* related pigments in the ponds of the McMurdo Ice Shelf, Antarctica. *Antarctic Science*, **1**, 125-131.

Howard-Williams, C., C.L. Vincent, P. Broady and W.F. Vincent. 1986. Antarctic stream ecosystems: variability in environmental properties and algal community structure. *Internationale Revue der Gesamte Hydrobiologie*, **71**, 511-544.

Huang, S., H.N. Pollack and P.-Y. Shen. 2000. Temperature trends over the past five centuries reconstructed from borehole temperatures. *Nature*, **403,** 756-758.

Hunt, H.W. and D.H. Wall. In press. Modeling the effects of loss of soil biodiversity on ecosystem function. *Global Change Biology*.

Iwata, H., S. Tanabe, N. Sakai and R. Tatsukawa. 1993. Distribution of persistent organochlorines in the oceanic air and surface seawater and the role of the ocean on their global transport and fate. *Environmental Science and Technology,* **27**, 1080-1098.

Jacka, T.H. 1990. Antarctic and Southern Ocean sea-ice and climate trends. *Annals of Glaciology*, **14**, 127-130.

Jacobs, S.S. (ed.). 1985. *Oceanology of the Antarctic Continental Shelf. Antarctic Research Series,* **43,** American Geophysical Union, Washington, D.C.

Jacobs, S.S. and J.C. Comiso. 1989. Sea ice and oceanic processes on the Ross Sea continental shelf. *Journal Geophysical Research*, **94**, 18,195-18,211.

Jacobs, S.S. and C.F. Giulivi. 1998. Interannual ocean and sea ice variability in the Ross Sea. In: Jacobs, S.S. and R. F. Weiss (eds.), *Ocean, Ice and Atmosphere: Interactions at the Antarctic Continental Margin, Antarctic Research Series*, **75**, American Geophysical Union, Washington, D.C., 135-150.

Jacobs, S.S. and R.F. Weiss (eds.). 1998. *Ocean, Ice and Atmosphere at the Antarctic Continental Margin. Antarctic Research Series,* **75**, American Geophysical Union, Washington, D.C., 135-150.

Jeffries, M.O. and W.F. Weeks. 1992. Structural characteristics and development of sea ice in the western Ross Sea. *Antarctic Science*, **5**, 63-75.

Jeffries, M.O. and U. Adolphs. 1997. Early winter snow and ice thickness distribution, ice structure and development of the western Ross Sea pack ice between the ice edge and the Ross Ice Shelf. *Antarctic Science,* **9**, 188–200.

Jeffries, M.O. and N. Kozlenko. In press. Buoy Deployments in the Ross Sea Pack Ice, 1998 and 1999. International Programme for Antarctic Buoys, World Climate Research Programmme/World Meteorological Organization (WCRP/WMO), Geneva, Switzerland.

Jeffries, M.O., W.F. Weeks, R.A. Shaw and K. Morris. 1993. Structural characteristics of congelation and platelet ice and their role in the development of antarctic landfast sea ice. *Journal of Glaciology*, **39**, 223-238.

Jeffries, M. O., K. Morris, T. Maksym, N. Kozlenko and T. Tin. 2001a. Autumn sea ice thickness, ridging and heat flux variability in and adjacent to Terra Nova Bay, Ross Sea, Antarctica. *Journal of Geophysical Research,* **106**, 4437-4448.

Jeffries, M. O., H.R. Krouse, B. Hurst-Cushing and T. Maksym. 2001b. Snow ice accretion and snow cover depletion on Antarctic first-year sea ice floes. *Annals of Glaciology,* **33**, in press.

Jensen, J.R. 2000. *Remote Sensing of the Environment – an Earth Resource Perspective.* Prentice Hall, New Jersey, 544 pages.

Jmenez, B., M.C. Fossi, M. Nigro and S. Focardi. 1999. Biomarker approach to evaluating the impact of scientific stations on the antarctic environment using Trematomus bernacchii as a bioindicator organism. *Chemosphere*, **3**, 2073 - 2078.

Jones, S. J. and B. Hill. 2001. Structure of sea ice in McMurdo Sound, Antarctica. *Annals of Glaciology*, **33**, in press.

Kannan, K., S. Corsolini, T. Imagawa, T. Evans, S. Focardi and J. Giesy. 2000. Polychlorinated naphtalenes (PCNs) and Polychlorinated biphenyls (PCBs) in marine species including polar bear and Weddell seals from polar regions. *Proceedings of the SETAC 21st Annual Meeting,* Nashville, Tennessee, 12-16 November 2000, p. 192.

Kashimoto, T., H. Miyata, S. Kunita, T. Tung, S.T. Hsu, K.J. Chang, S.Y. Tang, G. Ohi, J. Nakagawa and S.I. Yamamoto. 1981. Role of polychlorinated dibenzofurans in Yusho (PCB poisoning). *Archives of Environmental Health*, **36,** 321.

Kellogg, T.B. and R.S. Truesdale. 1979. Late Quaternary paleoecology and paleoclimatology of the Ross Sea: the diatom record. *Marine Micropaleontology*, **4,** 137-158.

King, J.C. 1994. Recent climate variability in the vicinity of the Antarctic Peninsula. *International Journal of Climatology,* **14**, 357-369.

King, J.C. and S.A. Harangozo. 1998. Climate change in the western Antarctic Peninsula since 1945: Observations and possible causes. *Annals of Glaciology*, **27,** 571-575.

Kooyman, G.L. 1993. Breeding habitats of emperor penguins in the Western Ross Sea. *Antarctic Science*, **5,** 143-148.

Kooyman, G.L., and T.G. Kooyman. 1995. Diving behavior or emperor penguins nurturing chicks at Coulman Island, Antarctica. *Condor*, **97,** 536-549.

Kottmeier, S.T., S.M. Grossi and C.W. Sullivan. 1987. Sea ice microbial communities. VIII. Bacterial production in annual sea ice of McMurdo Sound, Antarctica. *Marine Ecology-Progress Series,* **35**, 175-186.

Kozlenko, N. and M.O. Jeffries. Ice dynamics in the Ross Sea, Antarctica, derived from GPS-equipped buoys. Unpublished MS to be submitted to *Journal of Geophysical Research.*

Kreutz, K.J., P.A. Mayewski, L.D. Meeker, M.S. Twickler, S.I. Whitlow and I.I. Pittalwala. 1997. Bipolar changes in atmospheric circulation during the Little Ice Age. *Science*, **277**, 1294-1296.

Kreutz, K.J., P.A. Mayewski, I.I. Pittalwala, L.D. Meeker, M.S. Twickler, and S.I. Whitlow. 2000. Sea-level pressure variability in the Amundsen Sea region inferred from a West Antarctic glaciochemical record. *Journal of Geophysical Research*, **105**(D3), 4047-4059.

Kreutz, K.J. and E.R. Sholkovitz. 2000. Major element, rare earth element, and sulfur isotopic composition of a high-elevation firn core: Sources and transport of mineral dust in central Asia. *Geochemistry, Geophysics, Geosystems,* **1,** (available in electronic format only – http://g-cubed.org).

Kurtz, D.D. and D.H. Bromwich. 1983. Satellite observed behavior of the Terra Nova Bay polynya. *Journal of Geophysical Research*, **88**, 9717-9722.

Kurtz, D.D., and D.H. Bromwich. 1985. A recurring, atmospherically forced polynya in Terra Nova Bay. In Jacobs, S.S. (ed.), *Oceanology of the Antarctic Continental Shelf, Antarctic Research Series*, **43**, American Geophysical Union, Washington, D.C., 177-201.

Lange, M.A., S. F. Ackley, P. Wadhams, G.S. Dieckmann and H. Eicken. 1989. Development of sea ice in the Weddell Sea. *Annals of Glaciology*, **12**, 92-96.

Lenihan, H.S. 1992. Benthic marine pollution around McMurdo station, Antarctica: a summary of findings. *Marine Pollution Bulletin*, **25**(9-12), 318-323.

Lenihan, H.S. and J.S. Oliver. 1995. Anthropogenic and natural disturbances to marine benthic communities in Antarctica. *Ecological Applications,* **5**(2), 311-326.

Lenihan, H.S., J.S. Oliver, J.M. Oakden and M.A. Stevenson. 1990. Intense and localized benthic marine pollution around McMurdo Station, Antarctica. *Marine Pollution Bulletin*, **21**(9), 422-430.

Leventer, A. and R.B. Dunbar. 1986. Factors influencing the distribution of diatoms and other algae in the Ross Sea. *Journal of Geophysical Research*, **101**, 18,489-18,500.

Leventer, A., E.W. Domack, S.E. Ishman, S. Brachfeld, C.E. McClennen and P.L. Manley. 1996. Productivity cycles of 200-300 years in the Antarctic Peninsula region: understanding linkages among the sun, atmosphere oceans, sea ice and biota. *Geological Society of America Bulletin*, **108**, 1626-1644.

Lewis, E.L. and R.G. Perkin. 1985. The winter oceanography of McMurdo Sound. In: Jacobs, S.S. (ed.), *Oceanology of the Antarctic Continental Shelf, Antarctic Research Series*, **42**, American Geophysical Union, Washington, D.C., 145-165.

Lewis, C.V.W., C.S. Davis and G. Gawarkiewicz. 1994. Wind forced biological-physical interactions on an isolated offshore bank. *Deep-Sea Research- Part II*, **41**(1), 51-73.

Leys, S.P. and N.R.J. Lauzon. 1998. Hexactinellid sponge ecology: growth rates and seasonality in deep water sponges. *Journal of Experimental Marine Biology and Ecology*, **230**(1), 111-129.

Licht, K.J, A.E. Jennings, J.T. Andrews and K.M. Williams. 1996. Chronology of late Wisconsin ice retreat from the western Ross Sea, Antarctica. *Geology*, **24**, 223-226.

Licht, K.J, N.W. Dunbar, J.T. Andrews and A.E. Jennings. 1999. Distinguishing subglacial till and glacial marine diamictons in the western Ross Sea, Antarctica: Implications for last glacial maximum grounding line. *Geological Society of America Bulletin*, **111**, 91-103.

Licht, K.J., N. Dunbar, A.E. Jennings and J.T. Andrews. 1999. Sedimentological evidence for the maximum extent of grounded ice in the western Ross Sea during the last glacial maximum. *Geological Society of America Bulletin*, **111**(1), 91-103.

Liu, W.T., T.L. Marsh, H. Cheng and L.J. Forney. 1997. Characterization of microbial diversity by determining terminal restriction fragment length polymorphism of genes encoding 16S rRNA. *Applied and Environmental Microbiology*, **63**, 4516-4522.

Lizotte, M.P. Submitted. The influence of sea ice on Ross Sea biogeochemical processes. In: DiTullio, G.R. and R.B. Dunbar (eds), *Biogeochemistry of the Ross Sea,* American Geophysical Union. *Antarctic Research Series*

Lizotte, M.P. and K.R. Arrigo. (eds.). 1998. *Antarctic Sea Ice: Biological Processes, Interactions and Variability. Antarctic Research Series,* **73**, American Geophysical Union. Washington D.C.

Lizotte, M.P. and C.W. Sullivan. 1991. Rates of photoadaptation in sea ice diatoms from McMurdo Sound, Antarctica. *Journal of Phycology,* **27**, 367-373.

Loeb, V., V. Siegel, O. Holm-Hansen, R. Hewitt, W. Fraser, W. Trivelpiece and S. Trivelpiece. 1997. Effects of sea-ice extent and krill or salp dominance on the antarctic food web. *Nature*, **387,** 897-900.

Loganathan, B.G. and K. Kannan. 1991. Time perspectives of organochlorine contamination in the global environment. *Marine Pollution Bulletin*, **22**(12), 582-584.

Loganathan, B.G. and K. Kannan. 1994. Global organochlorine contamination trends – an overview. *Ambio*, **23**(3), 187-191.

Londraville, R.L. and B.D. Sidell. 1990. Ultrastructure of aerobic muscle in Antarctic fishes may contribute to maintenance of diffusive fluxes. *Journal of Experimental Biology,* **150**, 205-220.

Lyons, W.B., C. Howard-Williams and I. Hawes (eds.). 1997. *Ecosystem Processes in Antarctic Ice-Free Landscapes.* Balkema Press, Rotterdam.

Lyons, W.B., A. Fountain, P.T. Doran, J.C. Priscu, K. Neumann and K.A. Welch. 2000. The importance of landscape position and legacy: the evolution of the Taylor Valley Lake District, Antarctica. *Freshwater Biology*, **43**, 355-368.

Maksym, T. and M.O. Jeffries. 2000. A one-dimensional percolation model of flooding and snow ice formation on Antarctic sea ice. *Journal of Geophysical Research,* **105**, 26,313-26,331.

Maksym, T. and M.O. Jeffries. 2001. Phase and compositional evolution of the flooded layer during snow ice formation on Antarctic sea ice. *Annals of Glaciology,* **33**, in press.

Mann, M.E., R.S. Bradley and M.K. Hughes. 1998. Global-scale temperature patterns and climate forcing over the past six centuries. *Nature,* **392**, 779-787.

Mann, M.E., J. Park and R.S. Bradley. 1995. Global interdecadal and century-scale climate oscillations during the past five centuries. *Nature,* **378**, 266-270.

Markgraf, V., T.R. Baumgartner, J.P. Bradubury, H.F. Diaz, R.B. Dunbar, B.H. Luckman, G.O. Seltzer, T.W. Swetnam and R. Villalba. 2000. Paleoclimate reconstruction along the Pole-Equator-Pole transect of the Americas (PEP 1). *Quaternary Science Reviews,* **19,** 125-140.

Marion, G.M., G.H.R. Henry, D.W. Freckman, G. Jones, M.H. Jones, J. Johnstone, E. Lévesque, U. Molau, P. Mølgaard, A.N. Parsons, J. Svoboda and R.A. Virginia. 1997. Open-Top Designs for Manipulating Field Temperature in High-Latitude Ecosystems. *Global Change Biology,* **3**, 20-32.

Masson, V., F. Vimuex, J. Jouzel, M. Delmotte, P. Ciais, C. Hammer, S. Johnsen, V.Y. Lopenkov, E. Mosley-Thompson, J.R. Petit, E.J. Steig, M. Stievenard and R. Vaikmae. 2000. Holocene climate variability in Antarctica based on 11 ice-core isotopic records. *Quaternary Research,* **54**, 348–358.

Matthews, K.A., E.J. Steig and M.H. Hermanson. 2001. Time series of organochlorine pesticides from ice cores. *Abstract Volume, Spring 2001 Meeting of the American Geophysical Union, Session OS51B, Ice Cores Paleoclimates, Glaciology, and Environmental Change.*

Mauri, M., E. Orlando, M. Nigro and F. Regoli. 1990. Heavy metals in the antarctic scallop *Adamussium colbecki (Smith). Marine Ecology Progress Series,* **67**, 27-33.

Mayewski, P.A, M.S. Twickler, S. Whitlow, L.D. Meeker, Q. Yang, J. Thomas, K. Kreutz, P.M. Grootes, D.L. Morse, E.J. Steig, E.D. Waddington, E.S. Saltzman, P.-Y.Whung and K. Taylor. 1996. Climate change during the last deglaciation in Antarctica. *Science,* **272**, 1636-1638.

Mayewski, P.A., J. Souney, K.J. Kreutz, V.I. Morgan, T. van Ommen and I. Goodwin. 2001. Ice core proxy for Antarctic atmospheric circulation over the last several hundred years. *Abstract Volume, Spring 2001 Meeting of the American Geophysical Union, Session OS51B, Ice Cores Paleoclimates, Glaciology, and Environmental Change.*

McKay, C.P., J.A. Nienow, M.A. Meyer and E.I. Friedmann. 1994. Continuous nanoclimate data (1985-1988) from the Ross Desert (McMurdo Dry Valleys) cryptoendolithic microbial ecosystem. In: Bromwich, D.H. and C.R. Stearns (eds.), *Antarctic Meteorology and Climatology: Studies Based on Automatic Weather Stations, Antarctic Research Series,* **61**, American Geophysical Union, Washington, D.C., 201-207.

McMinn, A., J. Skerritt, T. Trull, C. Ashworth and M. Lizotte. 1999. Nutrient stress gradient in the bottom 5 cm of fast ice, McMurdo Sound, Antarctica. *Polar Biology,* **21**, 220-227.

McKnight, D.M., A. Alger, C.M. Tate, G. Shupe and S. Spalding. 1998. Longitudinal patterns in algal abundance and species distribution in meltwater streams in Taylor Valley, Southern Victoria Land, Antarctica. In: Priscu, J.C. (ed.), *Ecosystem Dynamics in a Polar Desert, Antarctic Research Series,* **72**, American Geophysical Union Washington D.C., 109-128.

Meyerson, E.A., P.A. Mayewski, S.I. Whitlow, L.D. Meeker, K.J. Kreutz and M.S. Twickler. In review. The extratropical expression of ENSO recorded in a South Pole glaciochemical time series.

Moorhead, D., D.M. McNight and C.M. Tate. 1998. Modelling nitrogen transformations in Dry Valley Streams, Antarctica. In: Priscu, J.C. (ed.) *Ecosystem Dynamics in a Polar Desert. Antarctic Research Series,* **72**, American Geophysical Union Washington D.C., 141-151.

Moorhead, D.L., M.B. Burkins, P.T. Doran, A.G. Fountain, W.B. Lyons, D.M. McKnight, J.C. Priscu, R.A. Virginia and D.H. Wall. 1999. Ecological Legacies: Production, Persistence and Influence on Soil and Lake Ecosystems of the Antarctic Dry Valleys. *Bioscience,* **49**(12), 1009-1019.

Moorhead, D.L., P. Doran, A.G. Fountain, W.B. Lyons, D.M. McKnight, J.C. Priscu, R.A. Virginia and D.H. Wall. 1999. Ecological Legacies: Production, Persistence and Influence on Soil and Lake Ecosystems of the McMurdo Dry Valleys, Antarctica. *BioScience,* **49**, 1009-1019.

Moritz, R.E. 1988. Ross Sea data buoy project, 1986-1988. *Antarctic Journal of the U.S.*, **23**, 78-80.

Morris, K., M.O. Jeffries, N. Kozlenko and T. Tin. Late autumn ice concentration, thickness and ridging distributions in the Ross Sea. Unpublished MS submitted to *Journal of Glaciology*.

Morse, D.L., E.D. Waddington and E.J. Steig. 1998. Ice age storm trajectories inferred from radar stratigraphy at Taylor Dome, Antarctica. *Geophysical Research Letters*, **25**(17), 3383-3386.

Moylan, T.J. and B.D. Sidell. 2000. Concentrations of myoglobin and myoglobin mRNA in heart ventricles from Antarctic fishes. *Journal of Experimental Biology*, **203**, 1277-1286.

Nichols, P.D., A.C. Palmisano, M.S. Rayner, G.A. Smith and D.C. White. 1989. Changes in the lipid composition of Antarctic sea-ice diatom communities during a spring bloom: an indication of community physiological status. *Antarctic Science*, **1**, 133-140.

Nienow, J.A.C., C.P. McKay and E.I. Friedmann. 1988. The cryptoendolithic microbial environment in the Ross desert of Antarctica: mathematical models of the thermal regime. *Microbiology and Ecology*, **16**, 253-270.

Nigro, M. 1993. Nearshore population characteristics of the antarctic scallop Adamussium colbecki (Smith, 1902) at Terra Nova Bay (Ross Sea). *Antarctic Science*, **5**(4), 377-378.

Nigro, M., E. Orlando and F. Regoli. 1992. Ultrastructural localization of metal binding sites in the kidney of the Antarctic scallop, *Adamussium colbecki*. *Marine Biology*, **113**, 637-643.

Nigro, M., F. Regoli, R. Rocchi and E. Orlando. 1997. Heavy metals in Antarctic Molluscs. In: Battaglia, B., J. Valencia and D.W.H. Walton (eds.), *Antarctic Communities*, Cambridge University Press, London, 409-412.

O'Brien, K.M. and B.D. Sidell. 2000a. The interplay among cardiac ultrastructure, metabolism and the expression of oxygen-binding proteins in Antarctic fishes. *Journal of Experimental Biology*, **203**, 1287-1297.

O'Brien, K.M. and B.D. Sidell. 2000b. Quantification of diffusion distance within the spongy myocardium of hearts from Antarctic fishes. *Respiratory Physiology*, **122**, 71-80.

O'Connor, W.P., D.H. Bromwich, and J.F. Carrasco. 1994. Cyclonically forced barrier winds along the Transantarctic Mountains near Ross Island. *Monthly Weather Review*, **122**, 137-150.

Oliver, J.S. 1980. *Processes Affecting the Organization of Marine Soft-Bottom Communities in Monterey Bay, California and McMurdo Sound Antarctica*. PhD Dissertation, University of California, San Diego.

Osborn, A.M., E.R.B. Moore and K.N. Timmis. 2000. An evaluation of terminal-restriction fragment length polymorphism (T-RFLP) analysis for the study of microbial community structure and dynamics. *Environmental Microbiology*, **2**(1), 39-50.

Palmisano, A.C., J.B. SooHoo, R.L. Moe and C.W. Sullivan. 1987. Sea ice microbial communities. VII. Changes in under-ice spectral irradiance during the development of Antarctic sea ice microalgal communities. *Marine Ecology Progress Series*, **35**, 165-173.

Palmisano, A.C., M.P. Lizotte, G.A. Smith, P.D. Nichols, D.C. White and C.W. Sullivan. 1988. Changes in photosynthetic carbon assimilation in Antarctic sea-ice diatoms during the spring bloom: variation in synthesis of lipid classes. *Journal of Experimental Marine Biology and Ecology*, **116**, 1-13.

Parsons, A.N., J.E. Barrett, R.A. Virginia and D.H. Wall. In press. Carbon dioxide flux in Antarctic Dry Valley soils. *Bulletin of the Ecological Society of America*.

Peltier, W.R. 1998. Postglacial variation in the level of the sea: implications for climate dynamics and solid-earth geophysics. *Reviews of Geophysics*, **36**(4), 603-689.

Penrose, J.D., M. Conde and T.J. Pauly. 1994. Acoustic detection of ice crystals in Antarctic waters. *Journal of Geophysical Research*, **99**, 12,573-12,580.

Peterson, D. and C. Howard-Williams. 2001. The Latitudinal Gradient Project. Report of an Antarctica New Zealand Workshop. *Antarctica New Zealand Special Publication*, Christchurch, 46 pages.

Powers, L.E., M. Ho, D. W. Freckman, and R.A. Virginia. 1998. Distribution, community structure and microhabitats of soil biota along an elevational gradient in Taylor Valley, Antarctica. *Arctic and Alpine Research*, **30**, 133-141.

Priscu, J.C. and C.W. Sullivan. 1998. Nitrogen metabolism in Antarctic fast-ice microalgal assemblages. In: Lizotte, M.P. and K.R. Arrigo (eds.), *Antarctic Sea Ice: Biological Processes, Interactions and Variability, Antarctic Research Series*, **73**, 147-160.

Rau, G.H., D.G. Ainley, J.L. Bengtson, J.J. Torres and T.L. Hopkins. 1992. N-15/N-14 and C-13/C-12 in Weddell Sea Birds, Seals, and Fish - Implications for Diet and Trophic Structure. *Marine Ecology-Progress Series,* **84,** 1-8.

Raymond, J.A., C.W. Sullivan and A.L. DeVries. 1994. Release of an ice-active substance by Antarctic sea ice diatoms. *Polar Biology,* **14**, 71-75.

Regoli, F., S. Corsolini, S. Olmastroni and M. Nigro. 2001. Susceptibility to oxidative stress in Adelie and Emperor penguin. *Polar Biology*, **24**, 365-369.

Regoli, F., M. Nigro, S. Bompadre and G. Wiston. 1999. Total oxidant scavenging capacity (TOSC) of microsomal and cytosolic fractions from Antarctic Arctic and Mediterranean Scallops: differentiation between three different potent oxidants. *Aquatic Toxicology*, **49**, 13-25.

Regoli, F., M. Nigro, E. Bertoli, G.B. Principato and E. Orlando. 1997. Defenses against oxidative stress in the Antarctic scallop Adamussium colbecki and effects of acute exposure to metals. *Hydrobiologia*, **355**, 139 - 144

Regoli, F., M. Nigro, M. Chiantore, V. Mastrangelo and G.W. Winston. 2001. Total Oxyradical Scavenging Capacity in Adamussium colbecki: seasonal variability and responses to UV radiation. *Polar Biology*, in press.

Regoli, F., M. Nigro, M.C. Chiantore, S. Gorbi and G. Wiston. 2000. Total oxidant scavenging capacity of Antarctic, Arctic and Mediterranean scallops. *Italian Journal of Zoology, supplement 1*, 85-94

Regoli, F., M. Nigro and E. Orlando. 1998. Lysosomal and antioxidant defences to metals in the Antarctic scallop Adamussium colbecki. *Aquatic Toxicology*, **40**, 375-392.

Regoli, F, G.B. Principato, E. Bertoli, M. Nigro and E. Orlando. 1997. Biochemical characterization of the antioxidant system in the scallop Adamussium colbecki, a sentinel organism for monitoring the Antarctic environment. *Polar Biology*, **17**, 251-258.

Risebrough, R.W. and G.M. Carmignani. 1972. Chlorinated hydrocarbons in Antarctic birds. In: Lawrence, P.B. (eds.), *Proceedings of a Colloquim on the Conservation Problems in Antarctica*, Allen Press, Lawrence, Canada, 63 pages.

Risebrough, R.W., P. Rieche, D.B. Peakall, S.G. Herman and M.N. Kirven. 1968. Polychlorinated biphenyls in the global ecosystem. *Nature*, **220,** 1098-1102.

Risebrough, R.W., W. Walker, T.T. Schmidt, B.W. DeLappe and C.W. Connors. 1976. Transfer of chlorinated biphenyls to Antarctica. *Nature*, **264,** 738-739.

Robinson, D.H., Z. Kolber and C.W. Sullivan. 1997. Photophysiology and photoacclimation in surface sea ice algae from McMurdo Sound, Antarctica. *Marine Ecology Progress Series,* **147**, 243-256.

Roemmich, D., and J. McGowan. 1995. Climatic warming and the decline of zooplankton in the California current. *Science*, **267**, 1324-1326.

Ross, R.M., E.E. Hofmann and L.B. Quetin (eds). 1996. Foundations for Ecological Research West Of the Antarctic Peninsula. *Antarctic Research Series* **70**, American Geophysical Union, Washington, D.C.

Ross, R.M., L.B. Quetin, K.S. Baker, M. Vernet and R.C. Smith. 2000. Growth limitation in young Euphausia superba under field conditions. *Limnology and Oceanography,* **45,** 31-43.

Ryan, J.J., D. Levesque, L.G. Panopio, W.F. Sun, Y. Masuda and H. Kuroki. 1993. Elimination of polychlorinated dibenzofurans (PCDFs) and polychorinated biphenyls (PCBs) from human blood in the Yusho and Yu-Cheng rice oil poisonings. *Archives of Environmental Contamination and Toxicology*, **24,** 504-512.

Safe, S. 1990. Polychorinated biphenyls (PCBs), dibenzo-*p*-dioxins (PCDDs), dibenzofurans (PCDFs) and related compounds: environmental and mechanistic considerations which support the development of Toxic Equivalency Factors (TEFs). *CRC Critical Review of Toxicol*ogy, **21,** 51-88.

Saino, N. and L. Guglielmo. 1999. ROSSMIZE Expedition: Distribution and Biomass of Birds and Mammals in the Western Ross Sea. In: Faranda L., L. Guglielmo and A. Ianora (eds.), *Ross Sea Ecology*, Springer-Verlag, Milan, 469-478.

Sala, O.E., F.S. Chapin III, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L.F. Huenneke, R. Jackson, A. Kinzig, R. Leemans, D. Lodge, H.A. Mooney, M. Oesterheld, N.L. Poff, M.T. Sykes, B.H. Walker, M. Walker and D.H. Wall. 2000. Global Biodiversity Scenarios for the Year 2100. *Science,* **287**, 1770-1774.

Sandweiss, D.H., J.B. Richardson, E.J. Reitz, E.B. Rollins and K.A. Maasch. 1996. Geoarcheological evidence from Peru for a 5000 year B.P. onset of El Niño. *Science,* **273**, 1531-1533.

Sansom, J. 1989. Antarctic surface temperature time series. *Journal of Climate*, **2**, 1164-1172.

Savarino, J., G. Michalski and M.H. Thiemens. 2001. Oxygen isotopic composition of nitrate trapped in Vostok ice core. *Abstract Volume, Spring 2001 Meeting of the American Geophysical Union, Session OS51B, Ice Cores Paleoclimates, Glaciology, and Environmental Change.*

SCAR 1993. *Antarctic Digital Database Version 2.* Scientific Committee on Antarctic Research, Cambridge (http://www.nerc-bas.ac.uk/public/magic).

Schmidt, S., W. Moskall, S.J. de Mora, C. Howard-Williams and W.F. Vincent. 1991. Limnological properties of Antarctic ponds during winter freezing. *Antarctic Science,* **3**, 373-388.

Shen, H.T. and N.L. Ackermann. 1990. Wave-induced sediment in coastal ice cover. In: Ackley, S.F. and W.F. Weeks (eds.), *Sea Ice Properties and Processes, CRREL Monograph,* **90-1**, 100-102.

Shipp, S., J.B. Anderson and E.W. Domack. 1999. Late Pleistocene-Holocene retreat of the West Antarctic Ice-Sheet system in the Ross Sea: Part 1 – Geophysical results. *Geological Society of America Bulletin*, **111**, 1486-1516.

Sidell, B.D. 1998. Intracellular oxygen diffusion: The roles of myoglobin and lipid at cold body temperature. *Journal of Experimental Biology,* **201**, 1119-1128.

Sidell, B.D., E.L. Crockett and W.R. Driedzic. 1995. Antarctic fish tissues preferentially catabolize monoenoic fatty acids. *Journal of Experimental Zoology,* **271**, 73-81.

Siegel, V. and V. Loeb. 1995. Recruitment of Antarctic krill *Euphausia superba* and possible causes for its variability. *Marine Ecology Progress Series,* **123,** 45-56.

Sinclair, B.J. and H. Sjursen. In press.Terrestrial invertebrate abundance across a habitat transect in Keble Valley, Ross Island, Antarctica. *Pedobiologia.*

Smith, R.C., D. Ainley, K. Baker, E. Domack, S. Emslie, B. Fraser, J. Kennett, A. Leventer, E. Mosley-Thompson, S. Stammerjohn and M. Vernet. 1999. Marine ecosystem sensitivity to climate change: Historical observations and paleoecological records reveal ecological transitions in the Antarctic Peninsula region. *Bioscience,* **49,** 393-404.

Smith, R.C., K.S. Baker, W.R. Fraser, E.E. Hofmann, D.M. Karl, J.M. Klinck, L.B. Quetin, B.B. Prezelin, R.M. Ross, W.Z. Trivelpiece and M. Vernet. 1995. The Palmer LTER: A Long-Term Ecological Research program. *Oceanography,* **8,** 77-86.

Smith, R.C., K.S. Baker, H.M. Dierssen, S.E. Stammerjohn and M. Vernet. 2001. Variability of primary production in an Antarctic marine ecosystem as estimated using a multi-scale sampling strategy. *American Zoologist*, in press.

Smith, R.C. and S.E. Stammerjohn. 2001. Variability of surface air temperature and sea ice extent in the western Antarctic Peninsula (WAP) region. *Annals of Glaciology*, in press.

Smith, W.O. (ed.). 1990a. *Polar Oceanography. Part A. Physical Science*. Academic Press, New York.

Smith, W.O.(ed.). 1990b. *Polar Oceanography. Part B. Chemistry, Biology and Geology.* Academic Press, New York.

Smith, W.O., Jr. and L.I. Gordon. 1997. Hyperproductivity of the Ross Sea (Antarctica) polynya during spring. *Geophysical Research Letters*, **24**, 233-236.

Smith, W.O., Jr., J. Marra, M.R. Hiscock and R.T. Barber. 2000. The seasonal cycle of phytoplankton biomass and primary productivity in the Ross Sea, Antarctica. *Deep-Sea Research,* **47**, 3119-3140.

Souney, J., P.A. Mayewski, L.D. Meeker, V. Morgan, T. van Ommen, and I.D. Goodwin. Near review. Behavior of the Davis Sea Low over the last 500 years.

Spaulding, S.A., D.M. McKnight, E.F. Stoermer and P.T. Doran. 1997. Diatoms in sediments of perennially ice-covered Lake Hoare, and implications for interpreting lake history in the McMurdo Dry Valleys of Antarctica. *Journal of Paleolimnology*, **17**(4), 403-420.

Spezie, G. and G.M.R. Manzella (eds.). 1999. *Oceanography of Ross Sea.* Springer, Milan. 286 pages.

Star, J. and J. Estes. 1990. Geographic Information Systems, Prentice Hall, N.J.

Steig, E.J. et al. 2000. Wisconsin and Holocene climate history from an ice core at Taylor Dome, Western Ross Embayment, Antarctica. *Geografiska Annaler,* **82A**(2-3), 213-235.

Steig, E.J., C.P. Hart, J.W.C. White, W.L. Cunningham, M.D. Davis and E.S. Saltzman. 1998. Changes in climate, ocean and ice-sheet conditions in the Ross embayment, Antarctica, at 6 ka. *Annals of Glaciology*, **27**, 305-310.

Steig, E.J., D.L. Morse, E.D. Waddington, M. Stuiver, P. Grootes, P.A. Mayewski, S.I. Whitlow and M.S. Twickler. 2000. Wisconsinan and Holocene climate history from an ice core at Taylor Dome, western Ross Embayment, Antarctica. *Geografiska Annaler*, **82A**(2-3), 213-235.

Stevens, M.I. and I.A. Hogg, personal communication (Thesis submitted, The University of Waikato, NZ).
Stirling, I. 1997. The importance of polynyas, ice edges, and leads to marine mammals and birds. *Journal of Marine Systems,* **10**, 9-21.
Stockton, W.L. 1984. The biology and ecology of the epifaunal scallop *Adamussium colbecki* on the west side of the McMurdo Sound, Antarctica. *Marine Biology,* **78**, 171-178.
Stoecker, D.K., D.E. Gustafson, M.M.D. Black and C.T. Baier. 1998. Population dynamics of microalgae in the upper land-fast sea ice at a snow-free location. *Journal of Phycology,* **34**, 60-69.
Sweeney, C. and 8 others. 2000a. Nutrient and carbon removal ratios and fluxes in the Ross Sea, Antarctica. *Deep-Sea Research*, **47**, 3395-3421.
Sweeney, C. and 8 others. 2000b. Biogeochemical regimes, net community production and carbon export in the Ross Sea, Antarctica. *Deep-Sea Research*, **47**, 3369-3394.
Swithinbank, C. 1988. *Satellite Image Atlas of Glaciers of the World:. Antarctica. United States Geological Survey Professional Paper 1386 B,* United States Government Printing Office, Washington, D.C.
Tanabe, S. and R.Tatsukawa. 1986. Distribution, behaviour and load of PCBs in the oceans. In: Waid J.S. (ed.), *PCBs and the Environment,* **I**, CRC Press, Boca Raton, Florida, 143-161.
Tanabe, S., H. Tanaka and R. Tatsukawa. 1984. Polychlorobiphenyls, DDT and hexachlorocyclohexane isomers in the Western North Pacific ecosystem. *Archives of Environmental Contamination and Toxicology*, **13,** 731-738.
Testa, J.W., G. Oehlert, D.G. Ainley, J.L. Bengtson, D.B. Siniff, R.M. Laws and D. Rounsevell. 1991. Temporal variability in Antarctic marine ecosystems: Periodic fluctuations in the phocid seals. *Canadian Journal of Fisheries and Aquatic Sciences,* **48,** 631-639.
Thompson, L.G., E. Mosley-Thompson, M.E. Davis, P.-N. Lin, K.A. Henderson, J. Cole-Dai, J.F. Bolzan and K.-B. Liu. 1995. Late Glacial State and Holocene tropical ice core records from Huascarán, Peru. *Science,* **269**, 46-50.
Thrush, S.F., R.D. Pridmore, R.G. Bell, V.J. Cummings, P.K. Dayton, R. Ford, J. Grant, J.E. Hewitt, A.H. Hines, T.M. Hume, S.M. Lawrie, P. Legendre, B.H. McArdle, D. Morrisey, D.C. Schneider, S.J. Turner, R. Walters, R.B. Whitlatch and M.R. Wilkinson. 1997. The sandflat habitat: Scaling from experiments to conclusions. *Journal of Experimental Marine Biology and Ecology,* **216**, 1-10.
Thrush, S.F., J.E. Hewitt, V.J. Cummings, M.O. Green, G.A. Funnell and M.R. Wilkinson. 2000. The generality of field experiments: interactions between local and broad-scale processes. *Ecology*, **81**, 399-415.
Tison, J.-L., R.D. Lorrain, A. Bouzette, M. Dini, A. Bondesan and M. Stiévenard. 1998. Linking landfast sea ice variability to marine ice accretion at Hells Gate Ice Shelf, Ross Sea. In: Jeffries, M.O. (ed.), *Antarctic Sea Ice: Physical Processes, Interactions and Variability, Antarctic Research Series*, **74**, American Geophysical Union, Washington, D.C., 375-407.
Treonis, A.M., D.H. Wall and R.A. Virginia. 1999. Invertebrate biodiversity in Antarctic dry soils and sediments. *Ecosystems*, **2**, 482-492.
Treonis, A.M., D.H. Wall and R.A. Virginia. 2000. The use of anhydrobiosis by soil nematodes in the Antarctic Dry Valleys. *Functional Ecology*, **14,** 460-467.
Trodahl, H.J. and R.G. Buckley. 1990. Enhanced ultraviolet transmission of Antarctic sea ice during the Austral spring. *Geophysical Research Letters,* **17**, 2177-2179.

Tyler, S.W., P.G. Cook, A.Z. Butt, J.M. Thomas, P.T. Doran and W.B. Lyons. 1998. Evidence of deep circulation in two perennially ice-covered Antarctic lakes. *Limnology and Oceanography*, **43**, 625-635.

Vacchi, M., M. La Mesa and M. Greco. 2000. The coastal fish fauna of Terra Nova Bay, Ross Sea, Antarctica. In: Faranda, F.M., L. Guglielmo and A. Ianora (eds.), *Ross Sea Ecology: Italiantartide Expeditions (1987-1995),* Springer-Verlag, Berlin, 457-468.

Van Bloem, S.J. 1996. *Exploring the biomass-productivity paradox: the case of the long-lived Antarctic scallop.* Masters Thesis. Environmental Science Graduate Program, The Ohio State University, Columbus, Ohio, 76 pages.

Van den Berg, M., L. Birnbaum, A.T.C. Bosvelt, B. Brunstorm, P. Cook, M. Feeley, J.P. Giesy, A. Hanberg, R. Hasegawa, S.W. Kennedy, T. Kubiak, J.C. Larsen, F.X.R. van Leewen, A.K.D. Liem, C. Nolt, R.E. Peterson, L. Poellinger, S. Safe, D. Schrenk, D. Tillit, M. Tysklind, M. Younes, F. Waern and T. Zacharewski. 1998. Toxic Equivalency Factors (TEFs) for PCBs, PCDDs, PCDFs, for human and wildlife. *Environmental Health Perspectives*, **106**(12), 775-792.

Vanney, J.R. and G.L. Johnson. 1985. GEBCO Baythmetric Sheet 5.18 (Circum-Antarctic). In: Jacobs, S.S. (ed.). *Oceanology of the Antarctic Continental Shelf. Antarctic Research Series,* **43**, American Geophysical Union, Washington, D.C., 1-5 (with 1:6,000,000 map).

Van Woert, M.L. 1999a. The wintertime expansion and contraction of the Terra Nova Bay polynya. In: Spezie, G. and G.M.R. Manzella (eds.), *Oceanography of the Ross Sea: Antarctica,* Springer-Verlag, New York, 145-164.

Van Woert, M.L. 1999b. Wintertime dynamics of the Terra Nova Bay polynya. *Journal of Geophysical Research*, **104**, 7753-7769.

Villinski, J.C., R.B. Dunbar and D.A. Mucciarone. 2000. Carbon 13/Carbon 12 ratios of sedimentary organic matter from the Ross Sea, Antarctica: A record of phytoplankton bloom dynamics. *Journal of Geophysical Research*, **105**, 14,163-14,172.

Vimeux, F., V. Masson, J. Jouzel, J.R. Petit, E.J. Steig, M. Stievenard, R. Vaikmae and J.W.C. White. In press. Holocene hydrological cycle changes in southern hemisphere documented in East Antarctic deuterium excess records. *Climate Dynamics.*

Vincent, W.F. 1988. *Microbial Communities of Antarctica.* Cambridge University Press, Cambridge, 304 pages.

Virginia, R.A. and D.H. Wall. 1999. How Soils Structure Communities in the Antarctic Dry Valleys. *BioScience*, **49**, 973-983.

Wall, D.H., G. Adams and A. Parsons. Soil biodiversity. In: Chapin, III, F.S., O.E. Sala and E. Huber-Sannwald (eds.), *Future Scenarios of Global Biodiversity*, Springer Verlag, New York.

Wall, D.H. and J.C. Moore. 1999. Interactions Underground: Soil Biodiversity, Mutalism and Ecosystem Processes. *BioScience*, **49**, 109-118.

Wall/Freckman, D. and R.A. Virginia. 1997. Low Diversity Antarctic Soil Nematode Communities: Distribution and Response to Disturbance. *Ecology,* **78**, 363-369.

Wall, D.H. and R.A. Virginia. 1999. Controls on Soil Biodiversity: Insights from Extreme environment. *Applied Soil Ecology,* **13**, 137-150.

Wall, D.H., M.A. Palmer and Paul V.R. Snelgrove. In press. Biodiversity in critical transition zones between terrestrial, freshwater and marine soils and sediments: processes, linkages, and management implications. *Ecosystems.*

Wania, F. and D. Mackay. 1993. Global fractionation and cold condensation of low volatitlity organochlorine compounds in polar regions. *Ambio,* **22**, 10-18.

Watanuki, Y., A. Kato, Y. Mori and Y. Naito. 1993. Diving performance of adelie penguins in relation to food availability in fast sea-ice areas: comparison between years. *Journal of Animal Ecology,* **62,** 634-646.

Waters, K.J. and R.C. Smith. 1992. Palmer LTER: A sampling grid for the Palmer LTER program. *Antarctic Journal of the U. S.,* **27**, 236-239.

Weatherly, J.W., J.E. Walsh and H.J. Zwally. 1991. Antarctic sea ice variations and seasonal air temperature relationships. *Journal of Geophysical Research,* **96**, 15,119-15,130.

Wharton. R.A. and P.T. Doran (eds.) 1999. McMurdo Dry Valley Lakes: Impacts of Research Activities. *Desert Research Institute -Special Publication,* University and Community College System of Nevada, USA, 54 pages.

Wharton Jr. R.A., B.C. Parker and G.M. Simmons. 1993. Distribution, species composition and morphology of algal mats in Antarctic Dry Valley Lakes. *Phycologia,* **22**, 355-365.

White, W.B. and R.G. Peterson. 1996. An Antarctic Circumpolar Wave in Surface Pressure, Wind, Temperature and Sea-Ice Extent. *Nature,* **380,** 699-702.

Woehler, E. 1993. *The Distribution and Abundance of Antarctic and Subantarctic Penguins.* SCAR, University Printing Service, Cambridge, England, 76 pages.

Wolters, V., W.L. Silver, D.E. Bignell, D.C. Coleman, P. Lavelle, W. van der Putten, P. de Ruiter, J. Rusek, D.H. Wall, D.A. Wardle, L. Brussaard, J.M. Dangerfield, V.K. Brown, K.E. Giller, D.U. Hooper, O. Sala, J. Tiedje and J.A. van Veen. 2000. Global change effects on above- and belowground biodiversity in terrestrial ecosystems: Interactions and implications for ecosystem functioning. *BioScience,* **50**, 1089-1099.

Xiping, D. and A.H. Knoll. 1996. Middle and Late Cambrian sponge spicules from Hunan, China. *Journal of Paleontology,* **70**(2), 173-184.

Zhang, X-G. and B.R. Pratt. 2000. A varied middle Ordovician sponge spicule assemblage from western Newfoundland. *Journal of Paleontology,* **74**(3), 386-393.

Zibordi, G., M. L. Van Woert, G.P. Meloni and I. Canossi. 1995. Intercomparisons of sea ice concentration from SSM/I and AVHRR data of the Ross Sea. *Remote Sensing Environment,* **53**, 145-152.

Zwally, H.J., J.C. Comiso and A.L. Gordon. 1985. Antarctic offshore leads and polynyas and oceanographic effects. In: Jacobs, S.S. (ed.), *Oceanology of the Antarctic Continental Shelf, Antarctic Research Series,* **43**, American Geophysical Union, Washington, D.C., 203-226.

Zwally, H.J., J.C. Comiso, C.L. Parkinson, W.J. Campbell, F.D. Carsey and P. Gloersen. 1983. *Antarctic Sea Ice, 1973-1976. Satellite Passive Microwave Observations,* NASA Special Publication - 459, National Aeronautics and Space Administration, Washington, D.C.

APPENDIX 3
PARTICIPANT LIST

Donald Atwood
Raytheon
4501 Mirage Drive
Castle Rock, CO 80104 USA
Email: atwooddo@polar.org

Andrea Bergamasco
Instituto Per lo Studio Della
Dinamica Delle Grandi Masse
ISDGM-CNR
S. Polo 1364
30125 Venezia
Italy
Email: andreab@isdgm.ve.cnr.it

Paul Berkman
Byrd Polar Research Center
The Ohio State University
108 Scott Hall
1090 Carmack Road
Columbus, OH 43210-1002 USA
Email: berkman.1@osu.edu

David Bromwich
Byrd Polar Research Center
The Ohio State University
108 Scott Hall
1090 Carmack Road
Columbus, OH 43210-1002 USA
Email: bromwich.1@osu.edu

Riccardo Cattaneo-Vietti
Dip.Te.Ris.
Università di Genova
Corso Europa, 26
16132 Genova
Italy
Email: catta@unige.it

Mariachiara Chiantore
Dip.Te.Ris.
Università di Genova
Corso Europa, 26
16132 Genova
Italy
Email: chiantor@dipteris.unige.it

Howard Conway
Department of Earth and Space Sciences
Box 351650-1650
University of Washington
Seattle, WA 98195 USA
Email: conway@geophys.washington.edu

Simonetta Corsolini
Dipartimento di Scienze Ambientali
University of Siena
I-53100 Siena
Italy
Email: corsolini@unisi.it

Daniel P. Costa
EMS A316
University of California
Santa Cruz, CA 95064 USA
Email: costa@biology.ucsc.edu

Guido di Prisco
IBPE/CNR
Via Marconi 12
I-80125 Naples
Italy
Email: diprisco@dafne.ibpe.na.cnr.it

Peter T. Doran
University of Illinois at Chicago
Department of Earth and Environmental Sciences
845 W. Taylor St.
Chicago, IL 60607-7059 USA
Email: pdoran@uic.edu

Joseph T. Eastman
Dept. of Biomedical Sciences
Ohio University
Athens, OH 45701-2979 USA
Email: eastman@ohiou.edu

Steve Emslie
Dept. of Biological Sciences
601 S. College Rd.
Univ. of North Carolina
Wilmington, NC 28403 USA
Email: emslies@uncwil.edu

Dr. Christian H. Fritsen
Division of Earth and Ecosystem Science
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512 USA
Email: cfritsen@dri.edu

John Hobbie
Marine Biological Laboratory
Woods Hole, MA USA
Email: jhobbie@mbl.edu

Clive Howard-Williams
Regional Manager NIWA (Ltd.)
Box 8602
Christchurch
New Zealand
Email: c.howard-williams@niwa.cri.nz

Martin O. Jeffries
Geophysical Institute
University of Alaska Fairbanks
903 Koyukuk Drive
P. O. Box 757320
Fairbanks, AK 99775-7320 USA.
Email: martin.jeffries@gi.alaska.edu

Stacy L. Kim
Moss Landing Marine Laboratories
8272 Moss Landing Road
Moss Landing, CA 95039 USA
Email: skim@mlml.calstate.edu

Kathy Licht
Geology Department
Indiana University - Purdue University
Indianapolis
723 W. Michigan St.
Indianapolis, IN 46202 USA
Email: klicht@iupui.edu

Michael P. Lizotte
Bigelow Laboratory for Ocean Sciences
P.O. Box 475
180 McKown Point Road
West Boothbay Harbor, ME 04575 USA
Email: MLizotte@bigelow.org

Kyger C. Lohmann
Department of Geological Sciences
University of Michigan
Ann Arbor, MI 48109 USA
Email: kacey@umich.edu

W. Berry Lyons
Byrd Polar Research Center
The Ohio State University
108 Scott Hall
1090 Carmack Road
Columbus, OH 43210-1002 USA
Email: lyons.142@osu.edu

Paul Mayewski
Institute for Quaternary and Climate Studies
Bryand Global Sciences Building
University of Maine
Orono, ME 00469 USA
Email: paul.mayewski@maine.edu

Carolyn Merry
Dept. of Civil and Environmental
Engineering and Geodetic Science
The Ohio State University
470 Hitchcock Hall
2070 Neil Avenue
Columbus, OH 43210 USA
Email: merry.1@osu.edu

Daryl Moorhead
University of Toledo
Toledo, OH 43606-3390 USA
Email: dmoorhe@uoft02.utoledo.edu

A. Pellegrini
ENEA - Progetto Antartide
C.R. Casaccia - Via Anguillarese 301
00060 S. Maria di Galeria - ROMA
Italy
Email: pellegrini_a@casaccia.enea.it

Polly Penhale
Office of Polar Programs
National Science Foundation
Arlington, VA 22230 USA
Email: ppenhale@nsf.gov

Ross D. Powell
Department of Geology and Environmental Geosciences
312 Davis Hall, Normal Rd
Northern Illinois University
DeKalb, IL 60115, USA
Email: ross@geol.niu.edu

John C. Priscu
Land Resources & Environmental Sciences
334 Leon Johnson Hall
Montana State University
Bozeman, MT 59717 USA
Email: jpriscu@montana.edu

Reed Scherer
Department of Geology and Environmental Geosciences
312 Davis Hall, Normal Rd
Northern Illinois University
DeKalb, IL 60115 USA
Email: reed@geol.niu.edu

Bruce D. Sidell
School of Marine Sciences
University of Maine
5741 Libby Hall
Orono, ME 04469-5741 USA
e-mail: BSidell@maine.edu

Walker O. Smith
Virginia Institute of Marine Science
College of William and Mary
Gloucester Pt, VA 23062 USA
Email: wos@VIMS.EDU

Ray Smith
University of California - Santa Barbara
Santa Barbara, CA USA
Email: ray@icess.ucsb.edu

Eric Steig
Quaternary Research Center and
Department of Earth & Space Sciences
351360 University of Washington
19 Johnson Hall
Seattle, WA 98195-1360 USA
Email: steig@geophys.washington.edu

Simon Thrush
National Institute of Water & Atmospheric Research
PO Box 11-115
Hamilton
New Zealand
Email: s.thrush@niwa.cri.nz

Serena Fonda Umani
Laboratory of Marine Biology
V. Piccard, 54
34010 Santa Croce - Trieste
Italy
Email: labbioma@univ.trieste.it

Diana Wall
Colorado State University
Natural Resource Ecology Laboratory
Fort Collins, CO 80523-1499 USA
Email: diana@NREL.colostate.edu

Ed Waddington
Department of Earth and Space Sciences
Box 351650-1650
University of Washington
Seattle, WA 98195 USA
Email: edw@geophys.washington.edu